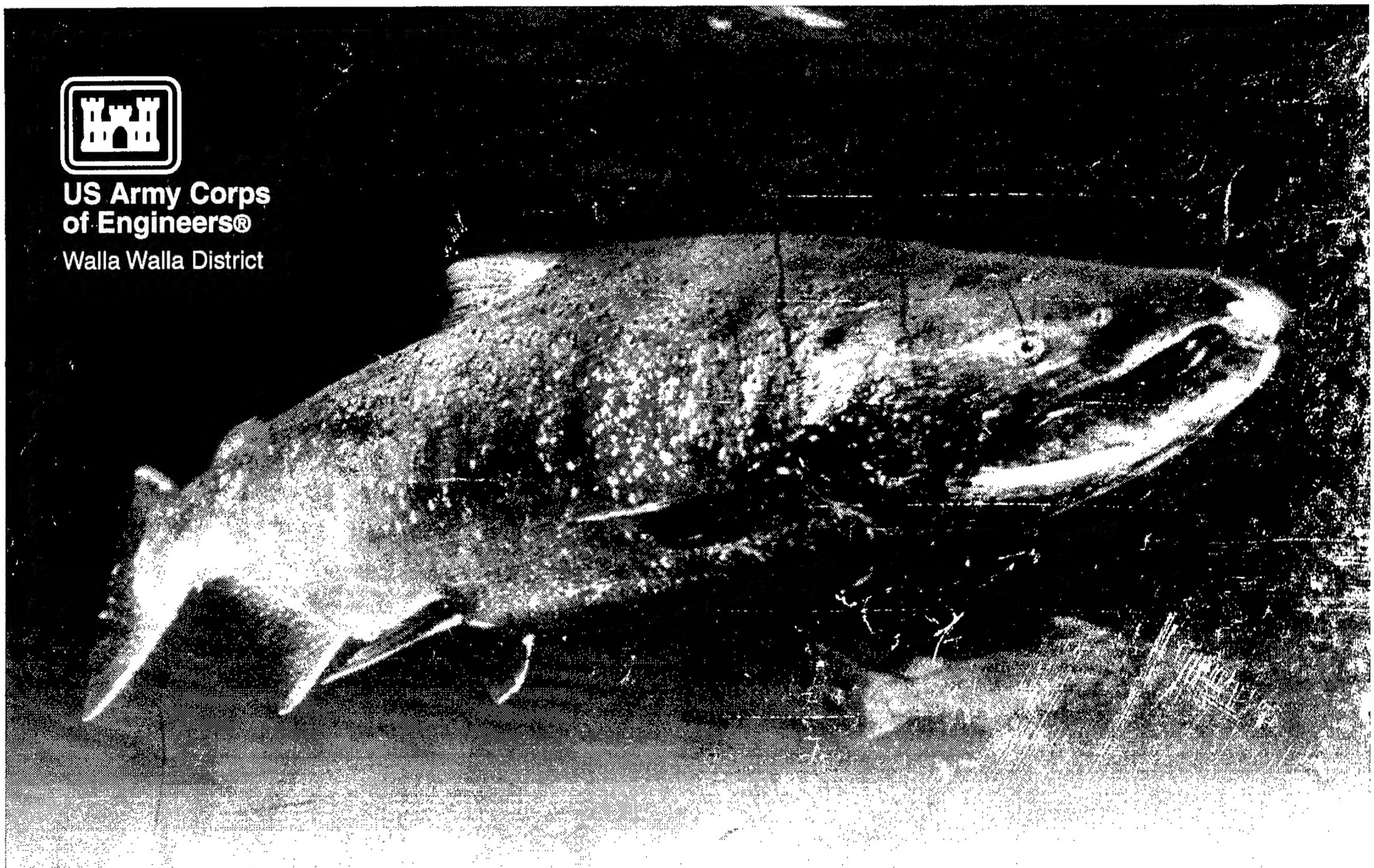

DRAFT
Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement

APPENDIX C
Water Quality

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13. ABSTRACT *(Maximum 200 words)*
The Corps of Engineers along with the Bonneville Power Administration, US Environmental Protection Agency, and US Bureau of Reclamation as cooperating agencies, analyzed four general alternatives intended to provide information on the technical, environmental, and economic effects of actions related to improving juvenile salmon passage. The four alternatives include Alternative 1 - Existing Conditions (the no-action alternative) and three different ways to further improve juvenile salmon passage. The action alternatives are: Alternative 2 - Maximum Transport of Juvenile Salmon, Alternative 3 - Major System Improvements, and Alternative 4 - Dam Breaching. Comparison of the alternatives by all of the factors assessed in the study has not offered a clear-cut recommendation at this time. It is the Corps of Engineer's intent to recommend a preferred plan of action in the Final FR/EIS.

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FEASIBILITY STUDY DOCUMENTATION

Document Title	
Summary to the Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement	
Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement	
Appendix A	Anadromous Fish
Appendix B	Resident Fish
Appendix C	Water Quality
Appendix D	Natural River Drawdown Engineering
Appendix E	Existing Systems and Major System Improvements Engineering
Appendix F	Hydrology/Hydraulics and Sedimentation
Appendix G	Hydroregulations
Appendix H	Fluvial Geomorphology
Appendix I	Economics
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Appendix K	Real Estate
Appendix L	Lower Snake River Mitigation History and Status
Appendix M	Fish and Wildlife Coordination Act Report
Appendix N	Cultural Resources
Appendix O	Public Outreach Program
Appendix P	Air Quality
Appendix Q	Tribal Consultation/Coordination
Appendix R	Historical Perspectives
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Appendix T	Biological Assessment
Appendix U	Clean Water Act, Section 404(b)(1) Evaluation

The documents listed above, as well as supporting technical reports and other study information, are available on our website at www.nww.usace.army.mil. Copies of these documents are also available for public review at various city, county, and regional libraries.

FOREWORD

This appendix is one part of the overall effort of the U.S. Army Corps of Engineers (Corps) to prepare the Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement (FR/EIS).

Please note that this document is a DRAFT appendix and is subject to change and/or revision based on information received through comments, hearings, workshops, etc. After the comment period ends and hearings conclude a Final FR/EIS with Appendices is planned.

The Corps has reached out to regional stakeholders (Federal agencies, tribes, states, local governmental entities, organizations, and individuals) during the development of the FR/EIS and appendices. This effort resulted in many of these regional stakeholders providing input, comments, and even drafting work products or portions of these documents. This regional input provided the Corps with an insight and perspective not found in previous processes. A great deal of this information was subsequently included in the Draft FR/EIS and Appendices, therefore, not all the opinions and/or findings herein may reflect the official policy or position of the Corps.

STUDY OVERVIEW

Purpose and Need

Between 1991 and 1997, due to declines in abundance, the National Marine Fisheries Service (NMFS) made the following listings of Snake River salmon or steelhead under the Endangered Species Act (ESA) as amended:

- sockeye salmon (listed as endangered in 1991)
- spring/summer chinook salmon (listed as threatened in 1992)
- fall chinook salmon (listed as threatened in 1992)
- steelhead (listed as threatened in 1997)

In 1995, NMFS issued a Biological Opinion on operations of the Federal Columbia River Power System. The Biological Opinion established measures to halt and reverse the declines of these listed species. This created the need to evaluate the feasibility, design, and engineering work for these measures.

The U.S. Army Corps of Engineers (Corps) implemented a study after NMFS's Biological Opinion in 1995 of alternatives associated with lower Snake River dams and reservoirs. This study was named the Lower Snake River Juvenile Salmon Migration Feasibility Study (Feasibility Study). The specific purpose and need of the Feasibility Study is to evaluate and screen structural alternatives that may increase survival of juvenile anadromous fish through the Lower Snake River Project (which includes the four lowermost dams operated by the Corps on the Snake River—Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams) and assist in their recovery.

Development of Alternatives

The Corps completed an interim report on the Feasibility Study in December 1996. The report evaluated the feasibility of drawdown to natural river levels, spillway crest, and other improvements to existing fish passage facilities. Based in part on a screening of actions conducted in the interim report, the study now focuses on four courses of action:

- Existing conditions (currently planned fish programs)
- System improvements with maximum collection and transport of juveniles (without major system improvements such as surface bypass collectors)
- System improvements with maximum collection and transport of juveniles (with major system improvements such as surface bypass collectors)
- Dam breaching or permanent drawdown to natural river levels for all reservoirs

The results of these evaluations are presented in the combined Feasibility Report (FR) and Environmental Impact Statement (EIS). The FR/EIS provides the support for recommendations that will be made regarding decisions on future actions on the Lower Snake River Project for passage of juvenile salmonids. This appendix is a part of the FR/EIS.

Geographic Scope

The geographic area covered by the FR/EIS generally encompasses the 140-mile long lower Snake River reach between Lewiston, Idaho and the Tri-Cities in Washington. The study area does slightly vary by resource area in the FR/EIS because the affected resources have widely varying spatial characteristics throughout the lower Snake River system. For example, socioeconomic effects of a permanent drawdown could be felt throughout the whole Columbia River Basin region with the most effects taking place in the counties of southwest Washington. In contrast, effects on vegetation along the reservoirs would be confined to much smaller areas.

Identification of Alternatives

Since 1995, numerous alternatives have been identified and evaluated. Over time, the alternatives have been assigned numbers and letters that serve as unique identifiers. However, different study groups have sometimes used slightly different numbering or lettering schemes and this has lead to some confusion when viewing all the work products prepared during this long period. The primary alternatives that are carried forward in the FR/EIS currently involve four major alternatives that were derived out of three major pathways. The four alternatives are:

Alternative Name	PATH[1/] Number	Corps Number	FR/EIS Number
Existing Conditions	A-1	A-1	1
Maximum Transport of Juvenile Salmon	A-2	A-2a	2
Major System Improvements	A-2'	A-2c	3
Dam Breaching	A-3	A-3a	4

[1/] Plan for Analyzing and Testing Hypotheses

Summary of Alternatives

The **Existing Conditions Alternative** consists of continuing the fish passage facilities and project operations that were in place or under development at the time this Feasibility Study was initiated. The existing programs and plans underway would continue. Project operations, including all ancillary facilities such as fish hatcheries and Habitat Management Units (HMUs) under the Lower Snake River Fish and Wildlife Compensation Plan (Comp Plan), recreation facilities, power generation, navigation, and irrigation would remain the same unless modified through future actions. Adult and juvenile fish passage facilities would continue to operate.

The **Maximum Transport of Juvenile Salmon Alternative** would include all of the existing or planned structural and operational configurations from the Existing Conditions Alternative. However, this alternative assumes that the juvenile fishway systems would be operated to maximize fish transport from Lower Granite, Little Goose, and Lower Monumental and that voluntary spill would not be used to bypass fish through the spillways (except at Ice Harbor). To accommodate this maximization of transport some measures would be taken to upgrade and improve fish handling facilities.

The **Major System Improvements Alternative** would provide additional improvements to what is considered under the Existing Conditions Alternative. These improvements would be focused on using surface bypass collection (SBC) facilities in conjunction with extended submersible bar screens (ESBS) and a behavioral guidance system (BGS). The intent of these facilities is to provide more effective diversion of juvenile fish away from the turbines. Under this alternative the number of fish collected and delivered to upgraded transportation facilities would be maximized at Lower Granite, the most upstream dam, where up to 90 percent of the fish would be collected and transported.

The **Dam Breaching Alternative** has been referred to as the "Drawdown Alternative" in many of the study groups since late 1996 and the resulting FR/EIS reports. These two terms essentially refer to the same set of actions. Because the term drawdown can refer to many types of drawdown, the term dam breaching was created to describe the action behind the alternative. The Dam Breaching Alternative would involve significant structural modifications at the four lower Snake River dams allowing the reservoirs to be drained and resulting in a free-flowing river that would remain unimpounded. Dam breaching would involve removing the earthen embankment sections of the four dams and then developing a channel around the powerhouses, spillways, and navigation locks. With dam breaching, the navigation locks would no longer be operational, and navigation for large commercial vessels would be eliminated. Some recreation facilities would close while others would be modified and new facilities could be built in the future. The operation and maintenance of fish hatcheries and Habitat Management Units (HMUs) would also change although the extent of change would probably be small and is not known at this time. Project development, design, and construction span a period of nine years. The first three to four years concentrate on the engineering and design processes. The embankments of the four dams are breached during two construction seasons at year 4-5 in the process. Construction work dealing with mitigation and restoration of various facilities adjacent to the reservoirs follows dam breaching for three to four years.

Authority

The four Corps dams of the lower Snake River were constructed and are operated and maintained under laws that may be grouped into three categories: 1) laws initially authorizing construction of the project, 2) laws specific to the project passed subsequent to construction, and 3) laws that generally apply to all Corps reservoirs.

BOUNDARIES

State

County

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GEOGRAPHIC INFORMATION SYSTEMS
Corps of Engineers
Walla Walla District

125,000 ACRES

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Lower Snake River
Juvenile Salmon Migration Feasibility Study

REGIONAL BASE MAP

1999

GIS Analysts & Graphic Assembly: Applied Technology Team (CENWW-PM-PD-E)
g:\regional\reg\plates\lsr\jsmels\lsrg\lsrgbmgm.dgn:GISFILE PLOTTED: 25 OCT 1999

ABSTRACT

Appendix C, Water Quality, was prepared by Normandeau Associates, Inc. 25 Nashua Rd. Bedford, NH with input from the Walla Walla District Corps of Engineers.

This document describes the existing water quality conditions within the lower Snake River and the anticipated changes associated with each of the eight alternatives under consideration, including the four that are carried forward in the FR/EIS. It provides supporting information for the FR/EIS and details about changes in water quality associated with implementing each of the alternatives. An analysis of water quality conditions was conducted for each of the alternatives under consideration. This analysis included a review and comparison of existing water quality data collected from various locations on the lower Snake River going back to 1975, as well as data collected from key locations between 1994 and 1997. The more recent data were used to model biological productivity within the river in a free-flowing condition. Potential impacts associated with sediment transport and resuspension are analyzed, including results of a study of existing sediment grain size and chemical constituents.

US Army Corps
of Engineers®
Walla Walla District

Draft
Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement

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Appendix C
Water Quality

Produced by
Normandeau Associates, Inc.

Produced for
U.S. Army Corps of Engineers
Walla Walla District

Completed December 1999
Revised and released for review
with Draft FR/EIS
December 1999

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FIGURES

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ACRONYMS AND ABBREVIATIONS

ABA	attached benthic algae
AFODW	ash-free, oven dry weights
AMPA	aminomethylphosphonic acid
BGS	behavioral guidance system
BKD	bacterial kidney disease
BOR	Bureau of Reclamation
BPA	Bonneville Power Administration
BRD	Biological Resources Division
BRWG	Biological Requirements Work Group
BRZ	boat restricted zone
CBFWA	Columbia Basin Fish and Wildlife Authority
cfs	cubic feet per second
CoC	chemicals of concern
Corps	U.S. Army Corps of Engineers
CRFMP	Columbia River Fish Mitigation Plan
CWT	coded wire tag
DGAS	Dissolved Gas Abatement Study
DGS	dissolved gas supersaturation
DO	dissolved oxygen
Ecology	Washington Department of Ecology
EPA	U.S. Environmental Protection Agency
ES	Executive Summary
ESA	Endangered Species Act
ESBS	extended submersible bar screen
ESU	evolutionarily significant unit
FCRPS	Federal Columbia River Power System
Feasibility Study	Lower Snake River Juvenile Salmonid Migration Feasibility Study
FGE	fish guidance efficiency
FMS	fixed monitoring station
FR/EIS	Feasibility Report/Environmental Impact Statement
FTU	Formazin turbidity units
FWCA	Fish and Wildlife Coordination Act
GBD	gas bubble disease
GBT	gas bubble trauma
HMU	habitat management unit
IDEQ	Idaho Department of Environment Quality
IDFG	Idaho Department of Fish and Game
ISAB	Independent Scientific Advisory Board
KAF	thousand acre-feet
kcfs	thousand cubic feet per second
MAF	million acre-feet
MOP	minimum operating pool

ACRONYMS AND ABBREVIATIONS

NMFS	National Marine Fisheries Service
NTU	nephelometric turbidity units
NPPC	Northwest Power Planning Council
NYDEC	New York Department of Environmental Conservation
ODEQ	Oregon Department of Environmental Quality
ORP	oxidation-reduction potential
ppt	parts per trillion
RM	River Mile
SBC	surface bypass collection
SOR	System Operation Review
TDG	total dissolved gas
TEQ	toxicity equivalence quotient
TGP	total gas pressure
TKN	total kjeldahl nitrogen
TMDL	total maximum daily load
TMT	Technical Management Team
TP	total phosphorous
TPH	total petroleum hydrocarbon
TSS	total suspended solids
UI	University of Idaho
USGS	U.S. Geological Survey
WDOE	Washington Department of Ecology
WQRRS	Water Quality River Reservoir Systems
WSU	Washington State University

Executive Summary

This Appendix was prepared in support of the overall Feasibility Study/Environmental Impact Statement (FR/EIS) being developed as part of the Lower Snake River Juvenile Salmon Migration Feasibility Study. This study represents one of several ongoing efforts by the Army Corps of Engineers (Corps) to improve conditions for salmon along the lower Snake River. Specifically, the Corps is evaluating several alternatives, identified through the public and interagency review process, to develop the most reasonable and prudent means of improving passage for anadromous salmonids.

An analysis of water quality conditions was conducted for each of the eight alternatives under consideration, four of which are carried forward in the FR/EIS. This analysis included a review and comparison of existing water quality data collected from various locations on the lower Snake River going back to 1975, as well as data collected from key locations between 1994 and 1997. The more recent data were used to model biological productivity within the river in a free-flowing condition. In addition, potential impacts associated with sediment transport and resuspension were analyzed using results from a study of existing sediment grain size and chemical constituents.

This document describes the existing water quality conditions within the lower Snake River and the anticipated impacts on water quality associated with each alternative. It is intended to provide supporting information for the FR/EIS and to help the decision-maker understand the water quality impacts associated with implementing each of the alternatives under consideration.

The Snake River is the largest tributary to the Columbia River, comprising about 42 percent of the overall drainage area and about 18 percent of the water flow in the Columbia River system. From its origin in Yellowstone National Park to its confluence with the Columbia River near Pasco, Washington, the river flows slightly more than 1,609 km (1,000 miles). The lower Snake River, or the portion of the Snake River within the project study area, consists of a 225-km (140-mile) reach extending from the point of confluence with the Columbia River upstream to the Clearwater River near Lewiston, Idaho. Within this portion of the river is a series of large reservoir impoundments located above four dams (Ice Harbor, Little Goose, Lower Monumental, and Lower Granite), all of which were constructed between 1961 and 1975. These impoundments range in length from 45 to 64 km (28 to 40 miles) and are up to approximately 30 m (100 feet) in depth. Elevated water temperatures and total dissolved gas (TDG) supersaturation generally represent the primary water quality concerns related to fisheries in the lower Snake River. Other water quality concerns include elevated turbidity and nutrient levels resulting from irrigation return flows and episodic low dissolved oxygen levels in bottom waters due to the biological decay of organic matter settling out on the bottom.

Eight alternatives were under consideration to improve conditions for salmon on the lower Snake River. These alternatives are anticipated to have various effects on numerous water quality parameters, including temperature, total dissolved gas supersaturation, sediment transport and erosion, primary and secondary productivity, and the food web. The anticipated impacts are summarized for each alternative below.

Existing Conditions: Existing system (A-1, Alternative 1 in FR/EIS) and Maximize transport (A-2, Alternative 2 in FR/EIS) alternatives:

Water quality would not change under these alternatives. This applies to all alternatives. Reservoir areas would continue to age, with continued silt deposit, leading to an increase in eutrophic conditions.

Major System Improvement Alternatives A-2a (Maximize Transport), A-2b (Minimize transport) and A-2c (Adaptive Management, Alternative 3 in FR/EIS): These three alternatives would not cause major changes in water quality parameters or primary and secondary productivity compared to existing conditions.

Major System Improvement Alternative A-6a (Additional 1.0 MAF augmentation): The additional 1.0-million-acre-foot (MAF) flow augmentation would nearly triple flow augmentation volumes passing through the reservoirs. The additional flow would have limited ability to cool downstream waters and may, in fact, offset Dworshak Reservoir releases. Peak temperatures would likely be elevated, especially in low-flow periods, accompanied by earlier fall cooling. The increased flow augmentation could also increase involuntary spill, resulting in higher TDG supersaturation levels and longer periods when TDG is above the threshold. No other significant differences from the existing condition in the lower Snake River are anticipated with this alternative (upstream changes are examined in BOR [1999]).

Major System Improvement Alternative A-6b (Zero flow augmentation): The elimination of all flow augmentation would result in water temperatures in the lower Snake system that are more affected by meteorological conditions than the existing system. It is expected that there would be fewer days with elevated temperatures compared to existing conditions, and minor changes in TDG could result from fish improvements and elimination of flow augmentation. Effects on biota, including primary and secondary productivity, should be minimal.

Natural River Drawdown (Alternative A-3, Alternative 4 in FR/EIS): The natural river drawdown alternative would change the river system from a lake-like to riverine condition. Flows would increase, water depth would decrease, and shoreline areas would become exposed. According to water quality models of the lower Snake River, water temperatures would warm more quickly and earlier in the season and cool more quickly compared to existing conditions (Normandeau 1999a, Perkins and Richmond 1999). Peak temperatures would be higher than the existing system during low-flow conditions, but would be similar during average and high-flow years (Normandeau 1999a). The number of days when water temperatures exceed 20 ° C would be lower with the dams removed (Yearsley 1999). Variability in water temperatures would be increased with the removal of the dams (Perkins and Richmond 1999).

Primary productivity would likely increase as a result of increased light penetration and, in low-flow years, higher temperatures; however, attached benthic algae would become the dominant primary producers. Corresponding changes in the food web would be expected, with benthic herbivores such as chironomid and trichopteran larvae becoming more important, and energy transfer would be through a benthic rather than planktonic food web. In addition, a major effect would be associated with the transport of sediment that has accumulated behind each of the dams.

Total suspended solids and turbidity would increase in comparison to existing conditions, at least in the short term, with the potential to settle on the river bottom and alter existing benthic habitats. The release of other water quality constituents currently attached to bottom sediments represents additional concerns, including dioxin TEQ, total DDT, and manganese. These constituents were

found to exceed recommended water or sediment standards and are, therefore, considered chemicals of concern (CoC). However, results from the revised Columbia River System Operational Review (SOR) HEC-5Q modeling indicate that the resuspension and redeposition of total DDT and dioxin TEQ in sediments following natural river drawdown would not result in exceedance of any currently recommended sediment quality standards. In contrast, the results of the SOR modeling indicate that the concentration of manganese in the lower Snake River following the implementation of this alternative would exceed water quality standards for taste and odor, but would not exceed standards protective of human health. These exceedances would be experienced at each of the four reservoirs of the lower Snake River, where several irrigation withdrawals are located. Predicted manganese concentrations have not been deleterious to salmonids in laboratory testing. Predicted total DDT concentrations at Lower Granite Dam during the first year following dam breaching would nearly match chronic criteria, suggesting there is a potential for sub-lethal effects on salmonids. Predicted dioxin concentrations are not expected to exceed New York Department of Environmental Conservation (NYDEC) criteria; further, existing sediment concentrations are less than concentrations known to adversely affect salmonids.

The natural river drawdown alternative assumes two dams would be breached per year for 2 consecutive years. Further, it is assumed that 76 to 155 million cubic meters (100 to 150 million cubic yards) has accumulated behind the four lower Snake River dams, and that approximately 50 percent of the deposited sediment would move downstream over the first few years following dam breaching. The temperature predictions for the drawdown alternative rely upon results from the WQRRS model, which was originally intended to examine changes in productivity. Draft results from recent temperature modeling efforts by the U.S. Environmental Protection Agency (EPA) (Yearsley 1999) and the Pacific Northwest Laboratory (Perkins and Richmond 1999) are described to supplement WQRRS model results.

Analysis of the water quality data indicates that three of the eight alternatives would result in changes in water quality. This includes the major system improvement 1.0-MAF flow augmentation (Alternative A6a), the zero flow augmentation (Alternative A6b), and the natural river drawdown alternative (Alternative A3). The 1.0-MAF augmentation alternative would likely lead to elevated peak temperatures, earlier fall cooling, higher TDG supersaturation levels, and longer periods where the TDG supersaturation exceeds threshold values. The zero flow augmentation alternative would lead to a system where water temperatures are more sensitive to meteorological conditions and would likely have fewer days with elevated temperatures. The natural river drawdown alternative would change the system from a lake-like system to a riverine system. Water temperatures would warm more quickly and reach a higher peak during low-flow years, but would cool more quickly in the fall. Primary productivity would likely increase as a result of increased light penetration and, in low-flow years, higher temperatures; however, attached benthic algae would become the dominant primary producers, rather than plankton. Total suspended solids and turbidity would increase in comparison to existing conditions, at least in the short term, with the potential to settle on the river bottom and alter existing benthic habitats. In some locations, release of dioxin and total DDT from resuspended sediments would exceed sediment quality standards, and manganese concentrations would exceed water quality standards for taste and odor. Manganese and dioxin concentrations would likely not have adverse effects on salmonids. Total DDT concentrations at Lower Granite Dam are predicted to match the chronic criteria for salmonids.

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1. Introduction

This Appendix was prepared in support of the overall Feasibility Study/Environmental Impact Statement (FR/EIS) being developed as part of the Lower Snake River Juvenile Salmon Migration Feasibility Study. This study represents one of several ongoing efforts by the Army Corps of Engineers (Corps) to improve conditions for salmon along the lower Snake River. Specifically, the Corps is evaluating several alternatives, identified through the public and interagency review process, to develop the most reasonable and prudent means of improving passage for spawning and rearing anadromous salmonids.

The Lower Snake River Juvenile Salmon Migration Feasibility Study (Feasibility Study) has been underway since 1995, and numerous alternatives have been identified and evaluated during the last 4 years. Over time, the alternatives have been assigned numbers and letters that serve as unique identifiers. However, different study groups have sometimes used slightly different numbering or lettering schemes, and this has led to some confusion when viewing all the work products prepared during this long period. The primary alternatives that are carried forward in the FR/EIS currently involve four major concepts that were derived out of three major pathways. The four alternatives and corresponding pathways are:

Pathway Name	Alternative Name	PATH Number	Corps Number	FR/EIS Number
Existing System	Existing Conditions	A-1	A-1	1
Major System Improvements	Maximum Transport of Juvenile Salmon	A-2	A-2a	2
Major System Improvements	Major System Improvements	A-2'	A-2c	3
Natural River Drawdown	Dam Breaching	A-3	A-3a	4

The Existing Conditions Alternative consists of continuing the fish passage facilities and project operations that were in place or under development at the time that this Feasibility Study was initiated. The existing programs and plans underway would continue to meet the authorized purposes of the Lower Snake River Hydropower Project. Project operations, including all ancillary facilities such as fish hatcheries and habitat management units (HMUs) under the Lower Snake River Fish and Wildlife Compensation Plan (Comp Plan), recreation facilities, power generation, and irrigation would remain the same, unless modified through future actions. Adult and juvenile fish passage facilities would continue to operate.

The Maximum Transport of Juvenile Salmon Alternative would include all of the existing or planned structural and operational configurations from the Existing Conditions Alternative. However, this alternative assumes that the juvenile fishway systems would be operated to maximize fish transport and that voluntary spill would not be used to bypass fish through the spillways (except at Ice Harbor). To accommodate this transport, some measures would be taken to upgrade and improve fish handling facilities.

The Major System Improvements Alternative would provide additional improvements to what is considered under the Existing Conditions Alternative. These improvements would be focused on using surface bypass collection (SBC) facilities in conjunction with extended submersible bar screens (ESBS) and a behavioral guidance system (BGS) located in the turbine intakes. The intent of these facilities is to provide more effective diversion of juvenile fish away from the turbines. Under this alternative, the number of fish collected and delivered to upgraded transportation facilities would be maximized as in the Maximum Transport of Juvenile Salmon Alternative. A variety of options under this alternative could be implemented, depending upon results of ongoing or future tests of equipment, facilities, and approaches.

The Dam Breaching Alternative has been referred to as the "Drawdown Alternative" in many of the study groups since late 1996 and the resulting FR/EIS reports. These two terms essentially refer to the same set of actions. Because the term drawdown can refer to many types of drawdown, the term dam breaching was created to describe the action behind the alternative; reservoirs would be automatically evacuated or drawn down by the act of breaching. The Dam Breaching Alternative would involve significant structural modifications at the four lower Snake River dams, allowing the reservoirs to be drained and resulting in a free-flowing river that would remain unimpounded. Dam breaching would involve removing the earthen embankment sections of the four dams and then developing a channel around the powerhouses, spillways, and navigation locks. With dam breaching, the navigation locks would no longer be operational, and navigation for larger vessels would be curtailed. Some recreation facilities would close while others would be modified, and new facilities could be built in the future. The operation and maintenance of hatcheries and HMUs would also change, although the extent of change would probably be small and is not known at this time. Dam breaching activities would take at least 2 full years to complete after an estimated 5-year period necessary for preparation of a detailed design report and assessment of contracts.

The eight alternatives selected for further study in this Appendix fall into three main systems:

- Maintenance of Existing System
  - Alternative A1, Existing Conditions (Alternative 1 in FR/EIS)
  - Alternative A2 Maximum Transport (Alternative 2 in FR/EIS)
- Implementation of System Improvements
  - Alternative A2a, System Improvements with maximized transport
  - Alternative A2b, System Improvements with minimized transport
  - Alternative A2c, System Improvements with adaptive management (Alternative 3 in FR/EIS)
  - Alternative A6a, System Improvements with in-river migration and 1.0-MAF augmentation
  - Alternative A6b, System Improvements with in-river migration and no-flow augmentation
- Natural River Drawdown (Alternative 4 in FR/EIS)

The principal goal of these alternatives is to reduce the reservoir-associated salmon mortality resulting from either predation and/or dam passage (discussed in greater detail in the full FR/EIS document).

The primary objectives of this Appendix are to summarize the existing limnological/water quality, sediment quality, and primary productivity conditions throughout the lower Snake River and to describe the potential changes that may result from the various alternatives being considered, including changes to state water quality standards. This information will assist in the selection of the most prudent alternative for improving anadromous salmonid migration conditions. For each alternative evaluated, including the Existing System/Existing Condition Alternative, a description of both anticipated short-term effects (i.e., construction and/or transition period) and long-term effects is provided.

Section 3.0 of this document contains a detailed description of the existing water quality conditions and aquatic biology in the Lower Snake River System based on extensive data collected from 1994 to 1997. Since the completion of the Lower Granite Dam, the last of four hydropower dams completed in 1975, nearly the entire reach of the lower Snake River consists of a series of large impoundments, in sharp contrast to its former "free-flowing" riverine system. As a result, the physical, chemical, and biological nature of this river reach has changed. The lower-flow velocities within these impoundments not only extend time of travel through this reach but also result in increased sedimentation, lower turbidity, increased nutrient availability, and greater light penetration. This provides excellent growing conditions for algae, especially planktonic algae (i.e., phytoplankton). The aquatic food web has consequently changed in favor of planktonic consumers and fish species typical of open-water reservoir systems.

Section 4.0 describes the various proposed alternatives and the potential effects of these alternatives on the lower Snake River water quality and aquatic biology. The proposed drawdown alternative has the greatest potential to affect water quality. A major short-term effect is the re-suspension and downstream movement of sediment accumulated behind the four dams. During the initial transition period following dam breaching, heavy sediment loads can be expected to move downstream, affecting water quality and substrate conditions in the next downstream impoundment. The duration and magnitude of this impact on beneficial uses of the lower Snake and Columbia River waters are discussed. Over the long term, however, major changes in the lower Snake water quality are not expected, because most of the influences on water quality relate to the land-based activities that occur within the watershed and existing discharges located along the river. The aquatic biology and associated food web, however, will likely change to reflect aquatic communities more typical of riverine environments.

In 1994, a similar Water Quality Appendix was prepared as part of the Columbia River System Operation Review (SOR) EIS process. The objectives of that document were quite similar in providing a description of existing conditions and an assessment of future changes associated with various alternatives including reservoir drawdown (Bonneville Power Administration [BPA], 1995). However, this earlier study differs in that it focused on the entire Columbia River Basin, a broader range of alternatives, and was a description of existing conditions based primarily on pre-1990 water quality data. These data were collected as part of several long-term monitoring programs conducted by various state and federal agencies and universities. In this Appendix, the description of existing water quality conditions is based on the more recent data collected since 1994 by research teams

from the University of Idaho (UI), Washington State University (WSU), and National Marine Fisheries Service (NMFS) under contract with the Corps.

The most recent water quality data contain a broader list of parameters, including biological productivity data (Normandeau, 1999a). In addition, given the number of sampling stations and selected locations, these data provide a more synoptic view of existing conditions throughout the lower Snake River. This detail reveals the effects that the four hydropower dams may have on water quality, as well as those attributable to upstream and tributary contributions. The effects of the lower Snake River on the Columbia River System can also be more closely evaluated with this database, because sampling was conducted above and below the Snake River confluence. Comparisons of those data to other historical, long-term data are made wherever possible to identify any relevant historical trends. However, comparisons to natural free-flowing riverine conditions are difficult given that there is very limited pre-impoundment data available for the lower Snake River, aside from the water quality data collected in the five years prior to completion of Lower Granite Dam in 1975.

Predictions of future water quality conditions under the proposed alternatives were based on the results of previous and recent modeling efforts, including the previous SOR modeling of sediment movement and the more recent modeling of potential biological productivity and temperature changes under the proposed "free-flowing" drawdown scenario (Normandeau, 1999a). This more recent effort was carried out by a team of water quality experts using the Water Quality River Reservoir Systems (WQRRS) model to simulate changes in the hydrodynamics, temperature, and biological productivity under the proposed drawdown conditions. Additional temperature modeling has been conducted by EPA (Yearsley, 1999) and the Pacific Northwest Laboratory (Perkins and Richmond, 1999). The analysis of potential impacts in this appendix focused on those parameters that are most likely to have an effect on anadromous fish, as well as those that are most likely to be affected by reservoir drawdown.

2. Background

2.1 Project Study Area

The Snake River originates in western Wyoming at Yellowstone National Park, and flows approximately 1,609 km (1,000 miles) through the states of Idaho, Washington, and Oregon to its confluence with the Columbia River near Pasco and Burbank, Washington. It is the largest tributary to the Columbia River and drains an area of approximately 282,000 sq. km. (109,000 square miles), including most of Idaho, and portions of Oregon, Washington, Wyoming, Nevada, and Utah. The topography within the basin ranges from steep mountainous areas, mainly in the upper headwater areas, to extensive volcanic plateaus and plains that have been deeply incised by the river over geologic time. The Snake River flows through several different physiographic provinces including the Columbia Plateau/Basalt Plain, which extends east from the foothills of the Cascade Range in Washington and Oregon to western Idaho; the Snake River Plain, which extends from southeastern Oregon, across southern Idaho and northern Nevada and Utah; the Blue Mountains province, which extends from southeastern Washington to central Oregon; and, the Northern Rocky Mountains province, which encompasses much of Idaho and Wyoming (BPA, 1995). Elevations range from approximately 152 m (500 feet) along the gorges of the lower Snake River in the Columbia Plateau physiographic province to more than 3,048 m (10,000 feet) in the mountains (BPA, 1995). The geology primarily consists of basaltic and granitic rocks, and to a lesser extent consolidated sedimentary rocks and alluvium. Soils within the drainage area of the Snake River generally consist of young alluvial materials along the lower terraces of the river, and a fine wind deposited loess in large areas of uplands in the Columbia Plateau. In addition, areas of glacial outwash and lake-bed silts can be found in the Columbia Plateau, caused by past glacial activity. Soils within the Rocky Mountain province include a variety of parent materials, including metamorphic rock, as well as deposits of glacial drift, outwash, and alluvium (BPA, 1995).

The project area includes the lower Snake River drainage basin, associated tributaries, and a portion of the middle Columbia River (see Figure 2-1). The lower Snake River, the primary focus of this study, consists of a 225 k (140-mile) reach extending from the point of confluence with the Columbia River, upstream to the Clearwater River near Lewiston, Idaho. The Snake River flows into the study area from Hells Canyon in southern Idaho, and drops in elevation from approximately 2,438 to 152 m (8,000 feet to 500 feet) at the Columbia River. As the river flows through the Columbia Plateau, it is flanked by basalt cliffs and tallus slopes (Funk et al., 1985). The average width of the canyon floor is approximately 1,067 m (3,500 feet), and the surrounding land consists largely of rolling dry farmed wheatland (Funk et al., 1985). Annual precipitation ranges from 20 cm (8 inches) or less in much of the lower plains to more than 203 cm (80 inches) in the higher mountains (Laird, 1964).

Since the construction of four hydropower dams on this reach between the years of 1961 and 1975 (Ice Harbor, Little Goose, Lower Monumental, and Lower Granite), this river segment consists primarily of a series of large reservoir impoundments. These impoundments range from 45 to 64 k (28 to 40 miles) long and approximately 30 m (100 feet) deep. The most downstream dam, Ice

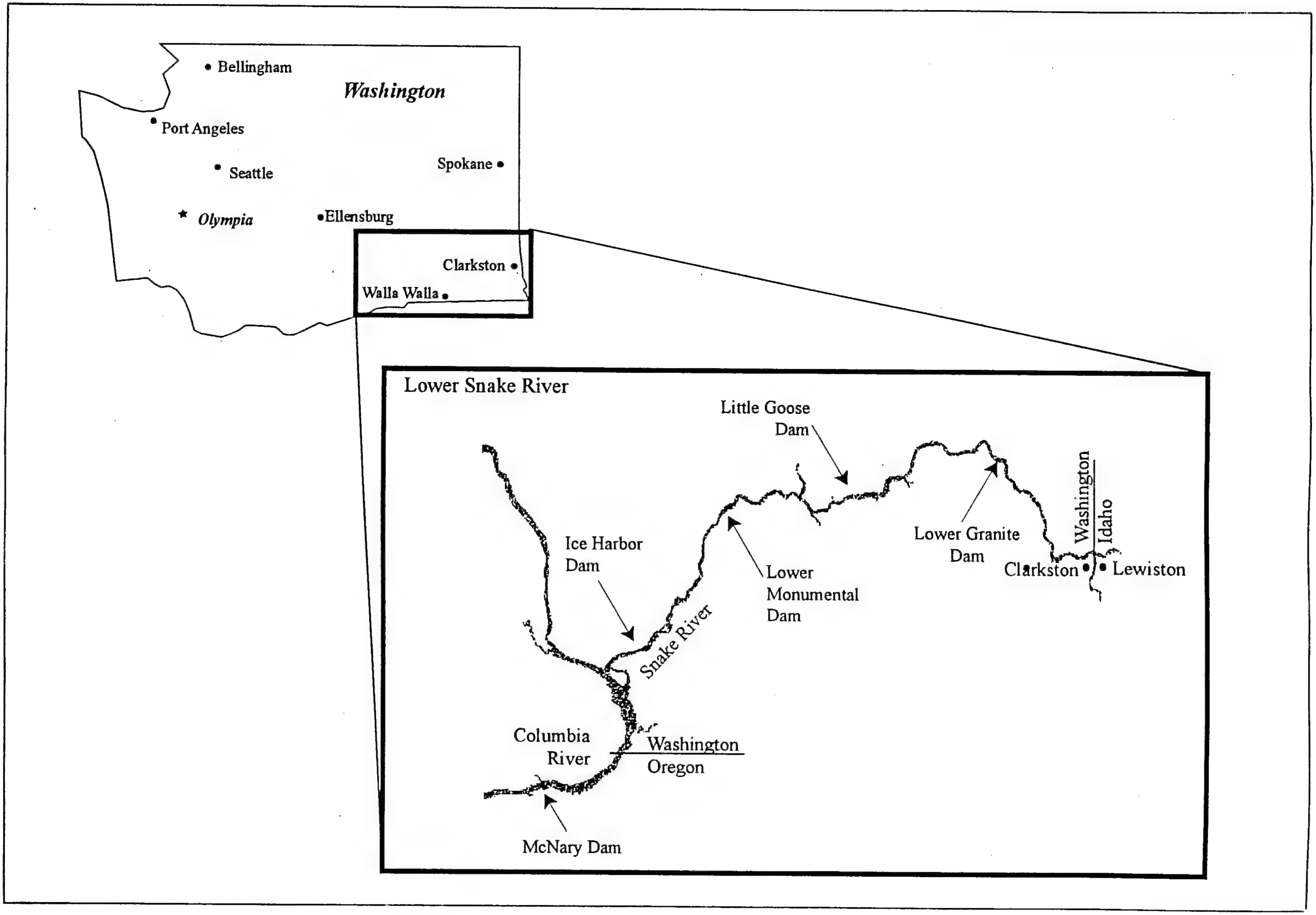


Figure 2-1. Lower Snake River Study Area

Harbor at river mile (RM) 9.7, was completed first in 1961 while the most upstream dam, Lower Granite at RM 107.5, was completed in 1975. The uppermost portions of the Lower Granite Reservoir extend upstream to RM 147 on the Snake River and to RM 6.5 on the Clearwater River. The project area also includes the McNary Reservoir (Lake Wallula) on the Columbia River, the next downstream impoundment, because any potential water quality changes or resuspension of sediments caused by the proposed alternatives are likely to affect water quality and/or sediment conditions downstream in this reservoir.

2.2 Summary of the Available Long-Term Water Quality Data

The previous Columbia River System Operation Review (SOR) documents, an earlier interagency study, provided an extensive review of the available long-term water quality data collected in the Columbia and Snake River basins prior to 1990 (BPA, 1995). There are eight long-term monitoring stations along the lower Snake River used by a number of state and federal agencies going back as far as 1975 (See Table 2-1). The sampling locations, frequency, and number of years sampled varies between the various agencies. Much of this monitoring focused on a few key parameters including temperature, pH, conductivity, turbidity, dissolved oxygen, and total dissolved gas supersaturation (TDG). The Corps monitored these parameters, as well as Secchi transparency within each of the reservoirs at a limited frequency of one to four times a year. Occasionally, other parameters such as hardness, total suspended solids (TSS), turbidity, and nutrient levels were measured. The U.S. Environmental Protection Agency (EPA) and the individual states conducted ambient water quality monitoring programs to primarily assess compliance status and trends. The Washington Department of Ecology (WDOE) sampled intensively (i.e., up to 10 samples per year) in 1975 for these same parameters plus fecal coliform bacteria. The U.S. Geological Survey (USGS) samples about once a year at two long-term monitoring stations on the lower Snake River (Anatone (RM 167) and Burbank (RM 2.2), Washington) and one on the Clearwater River at Spalding, Idaho (RM 11) where similar parameters were tested. The Universities of Washington and Idaho analyzed pre-impoundment water quality at the Lower Granite Dam area from 1970-1972 (Falter et al., 1973). Limited data have been collected, however, on concentrations of various toxics including heavy metals, pesticides, and other organic compounds.

2.3 Summary of Recent Water Quality Data Collected Within the Lower Snake River

In 1994, the Corps initiated an extensive sampling program throughout the Lower Snake River Basin with the assistance of research teams from WSU, NMFS, and the UI. The primary goal of this sampling program was to provide a more complete synopsis of the existing limnological and biological productivity conditions above, below, and throughout the lower Snake River reach and to assess the effects, if any, that the various dams have on water quality. Sampling was conducted both in the impoundments and in the "free-flowing" reaches and major tributaries. Sampling was also conducted in the Columbia River above and below the Snake River confluence (Table 2-2). Initially, in 1994 and 1995, data were collected on a monthly or bi-weekly basis within the lower Snake River system. The sampling frequency was increased in 1997 to bi-weekly monitoring through the growing season in both the lower Snake River and portions of the Columbia River. An extensive suite of parameters was sampled during these investigations, including many of the same

Table 2-1. Summary of Long-Term Water Quality Monitoring Data for Various Sampling Locations throughout the Project Area

River/Location	River Mile	Agency	Sampling Period	No. of Years	Sampling Frequency	Parameters[1/]
Columbia River						
McNary Dam, Tailwater	291	Corps	1993-pres.	7+	Apr-Sep (Cont)	B, TDG, Temp., DO
McNary Dam, Forebay	292	Corps	1984-pres.	15+	Apr-Sep (Cont)	B, TDG, Temp., DO
McNary Pool	295/306	Corps	1975-90	9	2-3/yr	Conventional parameters except TSS & TN
	295	EPA	1974-76	2	9-10/yr	Temp and DO only
Above Snake River Confluence	326	Corps	1997-98	9	2-3/yr	Conventional parameters except TSS & TN
Richland, WA	340	USGS	1979-90	12	1/yr	Conventional parameters except nutrients
		EPA	1975-92	18	6-9/yr	Temp., DO, Cond., Turbidity, ph, TP & OP
Snake River						
Burbank, WA	2.2	USGS	1960-69,72-78; 1979-1990	16	1/yr	Conventional parameters
	8.7					
Ice Harbor Dam, Tailwater	6.0	Corps	1991-pres.	9+	Apr-Sep(cont)	B, TDG, Temp., DO
Ice Harbor Dam, Forebay	9.7	Corps	1984-pres.	15+	Apr-Sep(cont)	B, TDG, Temp., DO
Ice Harbor Pool		Corps	1975-90	9	3/yr	Conventional parameters except TSS & TN
	18	EPA	1975	1	5/yr	Conventional parameters except TSS, Turb, Hardness
		WDOE	1975-90	15	6-10/yr	Conventional parameters except nutrients
L. Monumental Dam, Tailwater	40.6	Corps	1991-pres.	9+	Apr-Sep (cont)	B, TDG, Temp., DO
L. Monumental Dam, Forebay	41.6	Corps	1984-pres.	15+	Apr-Sep(cont)	B, TDG, Temp, DO,
L. Monumental Pool	44	Corps	1975	1	5/yr	Temp., Cond., DO, pH, turbidity
		EPA				
Little Goose Dam, Tailwater	69.5	Corps	1978-1992	15+	Apr-Sep(cont)	B, TDG, Temp., DO
Little Goose Dam, Forebay	70.3	Corps	1991-pres.	9+	Apr-Sep (cont)	B, TDG, Temp., DO
Little Goose Pool	83	Corps	1984-pres.	9	1/yr	Temp., Cond., DO, pH, turbidity
		EPA	1975	1	5/yr	
Lower Granite Dam, Tailwater	106.7	Corps	1991-pres.	9+	Apr-Sep(cont)	B, TDG, Temp., DO
Lower Granite Dam, Forebay	107.5	Corps	1984-pres.	15+	Apr-Sep(cont)	B, TDG, Temp., DO
Lower Granite-Lower Pool	1065	Corps	1978-89	9	1-2/yr	Conventional parameters
		USGS	1975-78	4	1/yr	Temp. & Cond. mostly
		EPA	1975-77	4	up to 25/yr	Temp., DO, Cond., Turb., pH, TP & OP
Lower Granite - Upper Pool	120	Corps	1978-92	9	1-2/yr	Temp., Cond.
		USGS	1974-77	3	1/yr	Conventional parameters except TSS, TP & OP
Anatone, WA	167	USGS	1974-pres.	20+	1/yr	Temp. & Cond. mainly; other parameters less frequently
		Corps	1999	1	Apr-Sep(cont)	B, TDG, Temp., DO
Clearwater River						
North Fork	0.5	Corps	1993-pres.	7+	Apr-Sep(cont)	B, TDG, Temp., DO
Peck	4.2	Corps	1996-pres.	3	Apr-Sep(cont)	B, TDG, Temp., DO
Spalding, ID	11	USGS	1974-pres.	20+	1/yr	Temp. & Cond. mainly; other parameters less frequently.
Lewiston	37.4	Corps	1996-pres.	3	Apr-Sep(cont)	B, TDG, Temp., DO

1/ Conventional parameters consists of temperature (Temp.), conductivity (Cond.), dissolved oxygen (DO), pH, total suspended solids (TSS), turbidity (Turb.), total nitrogen (TN), nitrate & nitrate (NO_2 and NO_3), total phosphorus (TP). Other parameters include total dissolved gas, measured continuously (TDG), and barometric pressure (B).

Table 2-2. Sampling Stations in the Clearwater River, Lower Snake River, Columbia River, Palouse River, and Tucannon River in 1997

Station Name	River	River Mile	Reach	Reach Type	Purpose	
CLW-11	*Clearwater*	~ 11	Spalding	Free-flowing	PP/Limno/ABA	Free-flowing Clearwater River, little controlled.
CLW-1		~ 1	Lewiston, Idaho	Free-flowing	Limno	Free-flowing Clearwater River before it merges with the Snake River. Included in previous studies and compliments the upstream primary productivity site. Also useful for eliciting any changes between stations.
SNR-148	*Snake*	~ 148	Asotin	Free-flowing	PP/Limno/ABA	Free flowing Snake River, little controlled.
SNR-140		~ 140	Lewiston/ Clarkston	Free-flowing	Limno	Free-flowing Snake River used in previous studies. Analogous benefits as the Clearwater 1 station.
SNR-129		~ 129	Lower Granite Reservoir	Transition zone	Limno	Visited in previous studies, and represents the transition between riverine and lacustrine environments.
S18		~ 118	Lower Granite Reservoir	Reservoir	PP/Limno/ABA	Represents the location in Lower Granite pool where complete mixing of the inflowing Snake and Clearwater Rivers has occurred. Previously visited and part of the primary productivity study.
SNR-108		~ 108	Above Lower Granite Dam	Reservoir	Limno	Site close to the forebay that was included in previous studies and located at deepest part of the reservoir.
SNR-106 SNR-105		~ 106/105	Below Lower Granite Dam	Free-flowing/ reservoir mix	PP/Limno/ABA	Hybrid of free-flowing/ reservoir; but more riverine.
SNR-83		~ 83/81	Little Goose Reservoir	Reservoir	PP/Limno/ABA	Only station that has consistently been sampled in Little Goose reservoir, and was included in the primary productivity study.
SNR-66		~ 68/67	Below Little Goose Dam	Free-flowing/ reservoir mix	PP/Limno/ABA	Hybrid of free-flowing/ reservoir; but more riverine.
SNR-50	*Snake*	~ 52/50	Lower Monumental Reservoir	Reservoir	PP/Limno/ABA	Snake River impoundment.
SNR-40		~ 40/37	Below Lower Monumental Dam	Free-flowing/ reservoir mix	PP/Limno/ABA	Hybrid of free-flowing/ reservoir, but more riverine.

Table 2-2. Sampling Stations in the Clearwater River, Lower Snake River, Columbia River, Palouse River, and Tucannon River in 1997 Page 2 of 2

Station Name	River	River Mile	Reach	Reach Type	Purpose	
SNR-18		~ 18	Ice Harbor Reservoir	Reservoir	PP/Limno/ABA	The only site that has routinely been sampled in the Ice Harbor reservoir.
SNR-6		~ 6	Below Ice Harbor Dam	Free-flowing/ reservoir mix	PP/Limno/ABA	Hybrid of free-flowing/ reservoir; but more riverine.
CLR-397	*Columbia*	~ 410/397	Priest Rapids Reservoir	Reservoir	PP/Limno/ABA	Impoundment and unconfounded by pollution inputs.
CLR-369		~ 369	Hanford Reach	Free-flowing	PP/Limno/ABA	True free-flowing river with similar gradient to the lower 140 miles of the Snake River.
CLR-326		~ 326	McNary Reservoir	Transition zone	Limno/ ABA	Similar to RM-129 on the Snake River in that it is at the upper end of the McNary reservoir and in the transition between riverine and lacustrine environments. Also upstream from the confluence of the Snake River.
CLR-306		~ 306	McNary Reservoir	Reservoir	Limno	Impoundment receiving Snake River flows and sampled in the past by the USACE.
CLR-295		~ 295	McNary Reservoir	Reservoir	PP/ Limno	The closest station to McNary Dam that has traditionally been sampled the USACE.
PAL-6	*Tributaries*	~ 6	Palouse River	Free-flowing	Limno	Has relatively small flow volume compared to the lower Snake River, but can have extremely high concentrations of nitrate and suspended solids.
TUC-1		~ 1	Tucannon	Free-flowing	Limno	Has less discharge than the Palouse River, but water quality unknown at beginning of study.

PP- Primary Productivity Sampling
LIMNO –Limnological Sampling
ABA-Attached Benthic Algae Sampling

conventional parameters used in the long-term monitoring studies such as pH, alkalinity, conductivity, dissolved oxygen, nutrients, TSS, and turbidity. Various anions and cations were also monitored including chloride, silica, sulfate, calcium, magnesium, sodium, and potassium. In addition, biochemical oxygen demand and sediment oxygen demand were also measured at selected locations as well as various biological parameters including chlorophyll *a*, phytoplankton, zooplankton, attached benthic algae, and other primary productivity indicators.

A range of hydrological conditions was encountered during the recent sampling program, including a relatively dry year in 1994 (ranging from 11 x 10^3 cubic feet per second (11 kcfs) to 93 kcfs and ranked near the lowest 10 percent of annual flows), an average year in 1995 (ranging from approximately 15 kcfs to 149 kcfs), and a wet year in 1997 (ranging from approximately 15 kcfs to 225 kcfs), based on historical streamflow data. The comparison of water quality conditions collected during a range of hydrologic conditions will assist in estimating how future conditions might be different, if at all, under various hydrologic conditions.

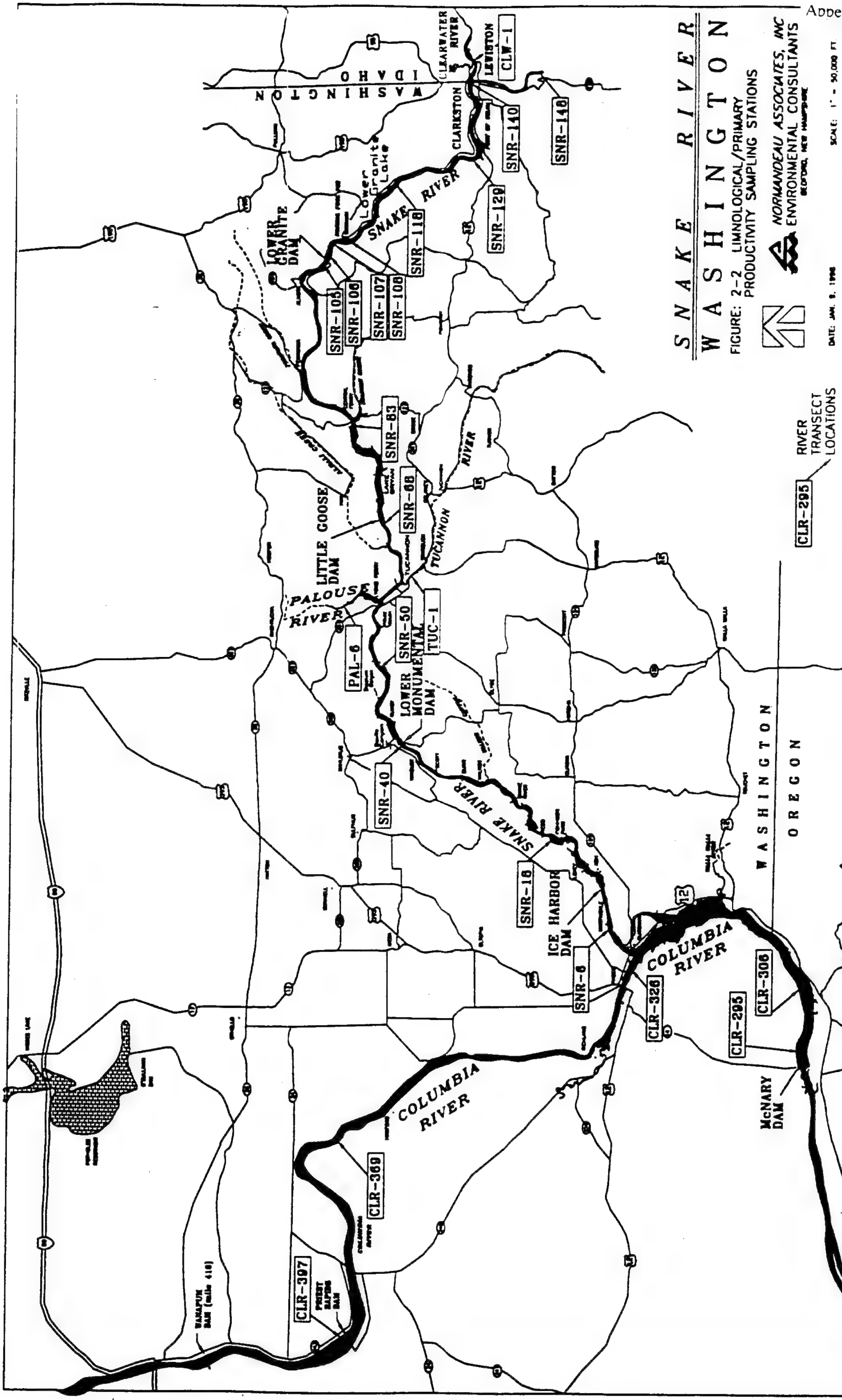
Researchers at WSU recently compiled much of these recent and long-term water quality data for the Columbia and Snake River basins into a computerized database using the Microsoft Access (Version 2.0) Program. This database was added to the existing NMFS database and represents the principal resource used in preparing a description of existing water quality conditions for this Appendix.

2.4 Description of Relevant Water Quality Sampling Station Locations

Figure 2-2 illustrates the locations of various water quality sampling stations throughout the project area. As many as 13 sampling stations were established along the mainstem of the lower Snake River. Upstream and downstream stations bracketed each of the four dams accounting for eight stations. Other key sampling stations include those representing the major tributary inputs to the lower Snake River, as well as two additional stations in the upper portions of the Lower Granite Reservoir at RMs 118 and 129. Stations SNR-140 and SNR-148 represented water quality conditions in the upper areas of lower Snake reach, upstream of the Clearwater River confluence and downstream of the middle Snake River reach. Station 148 is located in a free-flowing zone of the river that extends another 257 km (160 miles) upstream. The water quality at this location is still somewhat influenced by the biological and limnological conditions of the upstream impoundments as part of that from the Hells Canyon Dam Complex, as well as inputs from the Grande Ronde River and other tributaries.

Within the Columbia River, Stations CLR-295 and CLR-306 were located in the lower end of the McNary Reservoir, while Station CLR-326 was located just above the Snake River confluence and Station CLR-397 was just above Priest Rapids Dam.

Several free-flowing stream sections were sampled to compare water quality conditions between impounded and non-impounded reaches. In the Columbia River, a large free-flowing section near Hanford was sampled at Station CLR-369. Stations CLW-11, PAL-6, and TUC-1 were used to represent conditions in the Clearwater, Palouse, and Tucannon rivers, respectively.



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2.5 Sediment Quality Study

To assess the potential impacts from sediment transport associated with the drawdown alternative for this project, a study of existing sediment conditions was initiated in 1997. The study was a two-phase effort and encompassed the collection of sediment samples from all four reservoirs. During the first phase (Phase 1), sediment samples were collected and analyzed to determine the grain size of the materials. During the second phase (Phase 2), additional sediment samples were collected from selected locations and submitted for chemical analyses. A summary of the methodology used to analyze existing sediment quality is presented below, and details are provided in Normandeau, 1999b.

During Phase 1, sediment samples were collected along transects established across the reach of the lower Snake River and upstream of each dam. Three additional transects were sampled in the McNary Reservoir for a total of 54 transects. Sampling during Phase 1 focused on identifying those locations within the study reaches where the river bed sediment consisted primarily of very fine sand (0.062-0.125 mm) and silt/clay-size (<0.062 mm) particles (CH2M Hill, 1998). These locations were to be revisited during Phase 2 for the collection of sediment samples for the analysis of inorganic and organic chemical constituents. Only those areas where fine-grained sediments are present were of interest because it is assumed that only the fine-grained sediments will be eroded and transported by the free-flowing water if the drawdown alternative is implemented and because any organic or inorganic contaminants of concern would be most likely concentrated in the finer-grain-size fraction due to their physio-chemical properties.

Phase 2 of the study involved collection of sediment core samples from the areas identified in Phase 1 as having the highest percentage of fine particles. At each of the sediment sampling locations, river water samples were also collected. The river water samples were collected to perform elutriate tests and to determine existing water quality conditions.

The sediment samples were analyzed for a variety of parameters including metals, semivolatiles, herbicides, pesticides, organics, mercury, and nutrients. Elutriates were prepared for pH 4, ambient pH, pH 10 and for an exotic condition. The exotic elutriation was prepared having a pH of 2.6 and an oxidation-reduction potential (ORP) of 1,100 millivolts. Only the results of the ambient pH were used for the sediment evaluation.

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3. Affected Environment

3.1 Water Resources

The Snake River is the largest tributary to the Columbia River, comprising about 42 percent of the overall drainage area and about 18 percent of the water flow in the Columbia River System. From its origin in Yellowstone National Park to its confluence with the Columbia River near Pasco, Washington, the river flows slightly more than 1,609 km (1,000 miles). The Snake River watershed is about 282,000 km (109,000 square miles), comprising most of Idaho, the eastern part of Oregon, and lesser parts of Washington, Wyoming, Nevada, and Utah. The topography within the basin ranges from steep mountainous areas, mainly in the upper headwater areas, to extensive volcanic plateaus and plains that have been deeply incised by the river over geologic time. The geology primarily consists of basaltic and granitic rocks, and to a lesser extent consolidated sedimentary rocks and alluvium. Annual precipitation ranges from 20 cm (8 inches) or less in much of the lower plains to more than 203 cm (80 inches) in the higher mountains (Laird, 1964).

Historically, the average annual flow for the lower Snake River segment is 49.8 kcfs. Peak monthly flows average around 115 kcfs in June compared to an average seasonal monthly low flow of around 20 kcfs in September. The highest historical flow was 409 kcfs recorded in 1894 and the lowest historical flow was 10 kcfs and 6.6 kcfs recorded in 1931 and 1958, respectively (the latter occurring during construction of Brownlee Dam).

The Clearwater River, the largest tributary to the lower Snake River segment, historically contributes about 39 percent of the combined flow in the lower Snake River reach (BPA, 1995). The USGS maintains a gauging station at Spalding, Idaho, 18 km (11 miles) upstream from the Snake River. The peak monthly flow generally occurs in May and averages between 45 and 50 kcfs. The low-flow period typically occurs in September when the average monthly flows generally range between 3 and 5 kcfs. Flows from the Clearwater River, along with the recent additional releases from Dworshak Dam (RM 11), comprise close to 50 percent of the lower Snake River flows during periods of low flow.

The other principal tributaries to the lower Snake River include the Palouse River and the Tucannon River, which empty into the Snake River at RMs 60 and 65. The Palouse River is the larger of the two tributaries, but total flow contributions from these two tributaries are relatively minor and generally make up less than 1.5 percent of the Snake River flow. As discussed in Section 3.2.3, the relative low-flow contributions from these tributaries do not appear to have a major effect on overall water quality in the lower Snake River, although they may be locally significant.

3.2 Water Quality

3.2.1 General Description

The water quality of the Snake River reach is described by others to be excellent (Class A) to good (Class B) depending on the primary use and specific location (BPA, 1995). The middle section of the Snake River, above the Hells Canyon Reservoir complex, has been reported to show poorer water quality conditions than the lower sections below Brownlee Dam. The EPA has described the middle Snake River reach as having marginal water quality due primarily to nonpoint pollution

sources such as irrigation return flow and runoff from grazing areas (EPA, 1995). The Idaho Department of Health and Welfare has also reported an increasing trend in bacteria, nutrients, and suspended sediment concentrations as the river flows from Marsing (RM 24.0) to Weiser (RM 351.3). Although both the bacteria and sediment levels were noted to decrease as the river flows through the Hells Canyon Reservoir, elevated nutrient levels continued to be of concern downstream along with occasional low dissolved oxygen levels (BPA, 1995). Agriculture in the drainage basin has an impact on water quality both in terms of reduced flows due to irrigation withdrawals and increased nutrients, salts, sediments, and pesticides from the return flow. Agriculture comprises the largest nonpoint source of pollution and uses the largest amount of surface water within the basin. In 1964, more than 2,800,000 acres were estimated to be under irrigation (Laird, 1964), and irrigated agriculture is by far the largest segment of economic activity in the basin.

As the river flows through the Lewiston-Clarkston area (RM 14.0), the river water quality is potentially affected by the discharge of urban runoff and secondary treated wastewater effluent. The sources of these discharges are a pulp mill and municipal wastewater treatment plants at Lewiston, Idaho, and Clarkston, Washington.

The water quality of the Clearwater River is considered exceptional, better than the lower and middle portions of the Snake River. The Clearwater River, which contributes as much as 50 percent of the lower Snake River flow during low-flow periods, generally has a beneficial effect on the lower Snake River water quality. The USGS and recent Corps data indicate that the Clearwater River is quite low in dissolved solids, nutrients, and productivity and lacks any inorganic and organic contaminants (BPA, 1995). This is attributable to the largely granitic geology and minimal development or agriculture within its watershed. The Dworshak Dam, located on the North Fork of the Clearwater River, is a relatively large dam with a structural height of 219 m (717 feet) and a reservoir with an active storage capacity of slightly more than 2.0 million acre-feet (MAF). The reservoir is about 191 m (625 feet) deep at the forebay and has been characterized as oligotrophic (i.e., low productivity and nutrient limited), even though it has a relatively long retention time of 10 months. The reservoir thermally stratifies every year with a summer thermocline at about 12 to 15 m (40 to 50 feet) deep (BPA, 1995). Water temperatures below this depth remain constant throughout the year at about 4 to 5°C (39 to 41°F). In 1994, the Corps initiated controlled flow releases of this deep cooler water from about mid-July through August to reduce water temperatures in the lower Snake River. This added flow from the Clearwater River has had some effect on the water quality and biological productivity in the lower Snake River (Normandeau, 1999a).

Within the lower Snake River, elevated water temperatures and TDG generally represent the primary water quality concerns related to fisheries, particularly anadromous fish. Numerous studies and measures have been implemented over the years to alleviate elevated levels of both parameters. Spillway deflectors (flip-lips) have been installed at the face of spillways to reduce dissolved gas entrainment caused by the plunging effect into the stilling basins. As discussed earlier, cooler temperature water from within Dworshak Reservoir has been released during the summer months for temperature control. These flow augmentations generally lowered temperatures 2 to 3°C (3.6 to 5.4°F) in the Clearwater River and 1 to 2°C (2 to 4°F) in Lower Granite Reservoir, with diminishing effects downstream on the Snake River (Normandeau, 1999a; Karr et al., 1997). However, a relatively large release of water from Dworshak Reservoir in 1994 (a low-flow year) lowered

temperatures in the Clearwater River by as much as 10°C and lowered temperatures in Lower Granite Reservoir by as much as 5°C at 6 meters depth (Bennett et al., 1997).

Other water quality concerns include elevated turbidity and nutrient levels resulting from irrigation return flows, and episodic low dissolved oxygen levels in bottom waters due to the biological decay of organic matter settling out on the bottom. Increased nutrient concentrations can lead to greater productivity in the impoundments, reduced water clarity, and lower dissolved oxygen levels in the bottom waters. Extensive algal blooms have been noted to periodically occur throughout the lower Snake River and up into the Clearwater River (Normandeau, 1999a). These blooms are often made up of blue-green algae, which proliferate aggressively and are potentially toxic to certain aquatic life species. These are all symptoms of eutrophy, which is indicative of declining water quality.

3.2.2 Water Quality Standards

The states of Washington and Oregon have established surface water quality standards that are directly applicable to the proposed action. Oregon's water quality standards would only apply to possible downstream impacts in the Columbia River such as in the McNary Reservoir, a portion of which is within the state of Oregon. In addition, the state of Idaho also has water quality standards that may apply to any potential water quality changes that may occur in the uppermost portion of the Lower Granite Reservoir, above the Clearwater River confluence. Each of the state standards are typically based on, and sometimes more stringent than, the EPA water criteria that were developed for the protection of aquatic life and beneficial water uses.

According to the state of Washington's four-tiered water classification system, which ranges from Class AA (extraordinary) to Class C (fair), the lower Snake River is currently classified as Class A (excellent). Beneficial uses for Class A waters include water supply (domestic, industrial, agricultural); stock watering; fish and shellfish rearing, spawning and harvesting; wildlife habitat; recreation (primary contact); and commerce and navigation.

In protecting the various beneficial uses of surface waters, the states have imposed numerical standards for several key parameters including temperature, dissolved oxygen, total dissolved gas saturation, turbidity, pH, and fecal coliform bacteria. These are in addition to the federal aquatic life criteria and primary and secondary drinking water criteria that are also referenced and incorporated into the State Water Quality Standards (WAC 173-201A; Rev: Nov. 18, 1997). The numerical standards for each key water quality parameter are depicted in Table 3-1 discussed below. A detailed discussion of existing water quality in the lower Snake River within the context of the key water quality parameters is provided in Section 3.2.3.

3.2.2.1 Temperature

Washington's water quality standards specify that water temperatures in the lower Snake River shall not exceed 20°C (68°F) as a result of human activity. In addition, temperature increases due to human activity in the lower Snake River (i.e., below the Clearwater River) shall not exceed $t = 34/(T+9)$°C where t = change in temperature and T = background temperature. For example, if the background temperature is 20°C (68°F) then the maximum allowable temperature increase due to human activity would be 1.17°C (2.2°F). Above the Clearwater River (RM 139.3), increases over 0.3°C (0.54°F) caused by human activity from a single source are not allowed, and increases over

Table 3-1. Water Quality Standards in Oregon, Idaho, and Washington

Parameters	Oregon	Idaho	Washington
Temperature	≥ 20° C: No increase, single source ≤ 19.7° C: Increase < 0.28°C, single source < 19° C: Increase < 1.1° C, all sources	Maximum temp.: 13°C Daily average: < 9°C	Temp.: ≤ 20°C Temp. < 34 (T^1 + 9)° C
Dissolved Oxygen	≥ 90% saturation	≥ 6.0 mg/L, 30-day mean ≥ 4.7 mg/L, 7-day mean ≥ 3.5 mg/L, minimum ≥ 6.0 mg/L or 90% saturation (salmonid spawning)	≥ 8 mg/L
Total Dissolved Gas	≤ 110% saturation[3,5] ≤ 105% saturation[4]	≤ 110%	< 110%[3] < 120%, during salmon migration[5]
Turbidity	≤ 10% increase	≤ 5 NTU increase[6] < 10 NTU increase[7] < 50 NTU[8] < 10 NTU[9]	≤ 5 NTU increase[6] < 10 NTU increase[7]
PH	6.5 – 8.5	6.5 – 8.5	6.5 – 8.5
Fecal coliform	100 organisms/100mL[2]	100 organisms/100mL[2]	100 organisms/100mL[2]

1/ T = Background Temp.
2/ Geometric mean.
3/ Except when stream flow exceeds 10-year 7-day average flood frequency.
4/ In hatchery-receiving waters and when depth < 2 feet.
5/ Waivers to 120 percent in tailrace and 115 percent in forebay of downstream dam, with 125 percent maximum for 1–2 hours during voluntary spills.
6/ If background is ≤ 50 NTU.
7/ If background instantaneous measure is > 50 NTU.
8/ Instantaneous, outside mixing zone.
9/ 10 consecutive days.

1.1°C (2.0°F) from all activities are not allowed when the background stream temperature is over 20°C (68°F).

Oregon also allows no water temperature increases in the Columbia River, outside an assigned mixing zone, when the stream water temperature is at or above 20°C (68°F). When the river temperature is 19.7°C (67.5°F) or less, the Oregon standard dictates that no more than a 0.28°C (40°F) increase is allowed due to a single-source discharge. No more than a 1.1°C (32.5°F) increase is allowed by all sources when the stream temperature is 19°C (66°F) or less. Idaho has specific temperature criteria for salmonid spawning, with a maximum water temperature set at 13°C (55°F) and daily averages no greater than 9°C (48.2°F).

3.2.2.2 Dissolved Oxygen

In Washington, dissolved oxygen concentrations for Class A water must be equal to or greater than 8 mg/L during all times of the year. Oregon specifies at least 90 percent saturation for its portions of the Columbia River. Idaho requires the following minimum limits: at least 6.0 mg/L (30-day mean); 4.7 mg/L (7-day mean); 3.5 mg/L instantaneous minimum); and 6.0 mg/L or 90 percent of saturation (whichever is greater) for salmonid spawning purposes.

3.2.2.3 Total Dissolved Gas Supersaturation (TDG)

According to Oregon Administrative Rules, Chapter 340, relating to Water Quality Control, the standards for "the concentration of total dissolved gas relative to atmospheric pressure at the point of sample collection shall not exceed 110 percent of saturation, except when stream flow exceeds the 10-year, 7-day average flood. However, for hatchery-receiving waters and waters less than two feet in depth, the concentration of total dissolved gas relative to atmospheric pressure at the point of sample collection shall not exceed 105 percent of saturation." Also, in an adjacent portion of the rules it states that, "the liberation of dissolved gases, such as carbon dioxide, hydrogen sulfide, or other gases, in sufficient quantities to cause objectionable odors or to be deleterious to fish and other aquatic life, navigation, recreation, or other reasonable uses made of such water shall not be allowed."

According to Chapter 173-201 WAC, the state of Washington water quality standards for surface waters, the Columbia River, from the mouth to the Washington-Oregon border, "shall not exceed 110 percent of saturation at any point of sample collection." The water quality criterion for total dissolved gas does not apply when the stream flow exceeds the 7-day, 10-year flood frequency. In addition, a special exemption for salmonid migration has been promulgated that allows 120 percent during specific periods.

In recent years, the states of Oregon and Washington have been granting, at NMFS' request, standards waivers to allow the voluntary spill for fish passage to occur. The 110 percent limit was relaxed to 120 percent in the tailrace and 115 percent in the forebay of the next dam downstream, with a maximum of 125 percent for no more than one or two hours. The Oregon and Washington waivers have applied to the March 23 to August 31 period.

3.2.2.4 Turbidity

Washington and Idaho specify that increases in turbidity levels shall not exceed 5 nephelometric turbidity units (NTUs) when the background level is 50 NTU or less and no more than a 10 NTU

increase is allowed when background is more than 50 NTUs. In addition, the state of Idaho allows for a mixing zone and requires that the instantaneous level below this mixing zone not exceed 50 NTUs instantaneous measurement, or 25 NTUs for 10 consecutive days. Oregon simply specifies that no more than a 10 percent increase over background is allowed.

3.2.2.5 pH

All three states require pH levels to be within 6.5 and 8.5 pH units.

3.2.2.6 Bacteria

Fecal coliform bacteria levels must be less than a geometric mean value of 100 organisms/100 mL in all three states.

3.2.3 Summary of Existing Water Quality/Limnology Conditions

The following sections provide a synopsis of the relevant physical, chemical, and biological parameters that can be used to characterize water quality/limnological conditions within the lower Snake River system. This synopsis is based primarily on the recent sampling data collected by the WSU and UI between 1994 and 1997, although where available, some earlier data has been included in the discussion.

3.2.4 Hydrology and Meteorological Conditions

Figures 3-1 and 3-2 present combined monthly mean discharges for the Snake River at Lower Granite Dam from 1975 through 1977, and from 1994 through 1997, along with historical monthly averages from 1975 through 1997. In 1997, average monthly flows were considerably higher than the historical monthly averages throughout the growing season, especially between May and July.

Monthly average flows ranged from a high of about 170 kcfs in May to a low of approximately 25 kcfs in November and December. Flows in August and September of 1997 were nearly twice as high as the historical average flows of 20 to 25 kcfs for these months. In 1995, the mean monthly flows were very close to the historical monthly averages for the first half of the year, and reflect slightly wetter conditions during the summer and fall months. In 1994, average monthly flow levels were consistently below the historical averages with a high of about 75 kcfs during May, and a low of around 10 kcfs for much of August and September. The August and September flow levels were nearly 50 percent lower than historical averages for these months. The average flow data for 1975 through 1977 contained two years that had above-average flows (1975 and 1976), and one year (1977), which was primarily below average. Although the flow rates at the Ice Harbor Dam varied from Lower Granite Dam, the same seasonal flow pattern and annual variability can be seen in Figures 3-3 and 3-4. These figures depict the flow data at the Ice Harbor Dam for the same time periods.

Figure 3-5 illustrates the monthly mean air temperatures recorded at the Nez Perce weather station in Lewiston, Idaho, during the years of 1994-1997 in comparison to historical monthly averages. Differences in mean monthly temperatures between sampling years are not as dramatic relative to the fluctuations in flow conditions. In 1994, the mean monthly air temperatures were fairly close to normal except during the critical months of July, August, and September, when slightly warmer

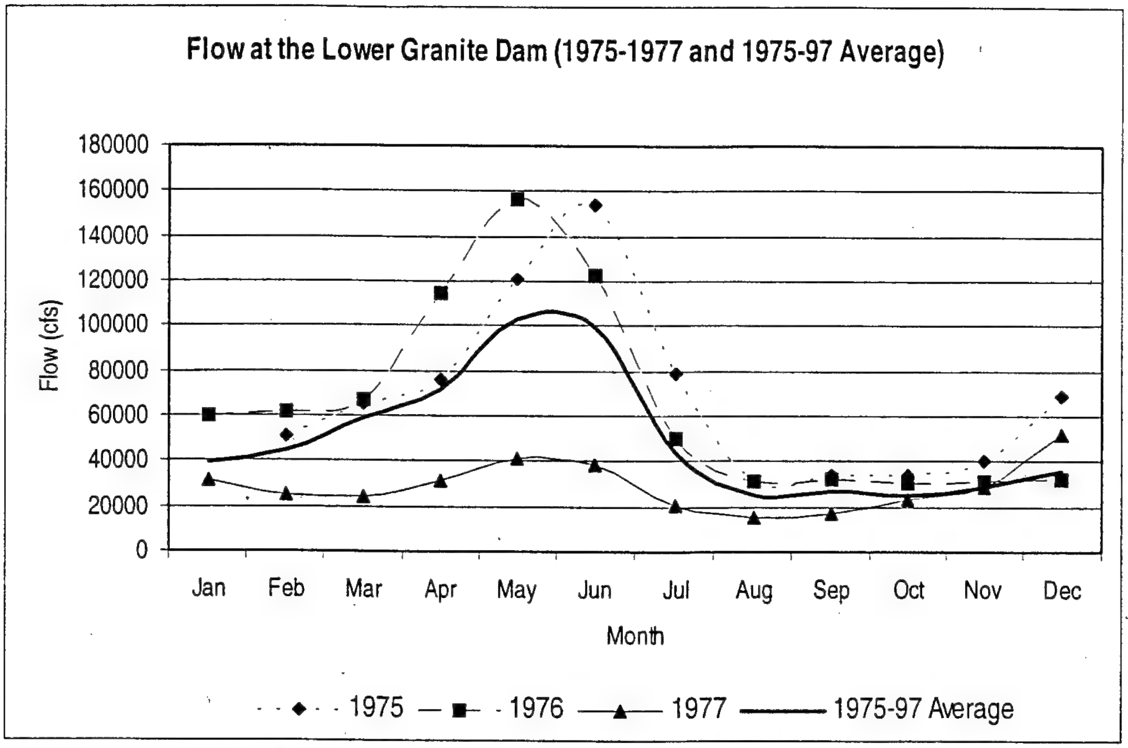

Figure 3-1. Monthly Mean Flow Data at Lower Granite Dam for the Years 1975-77

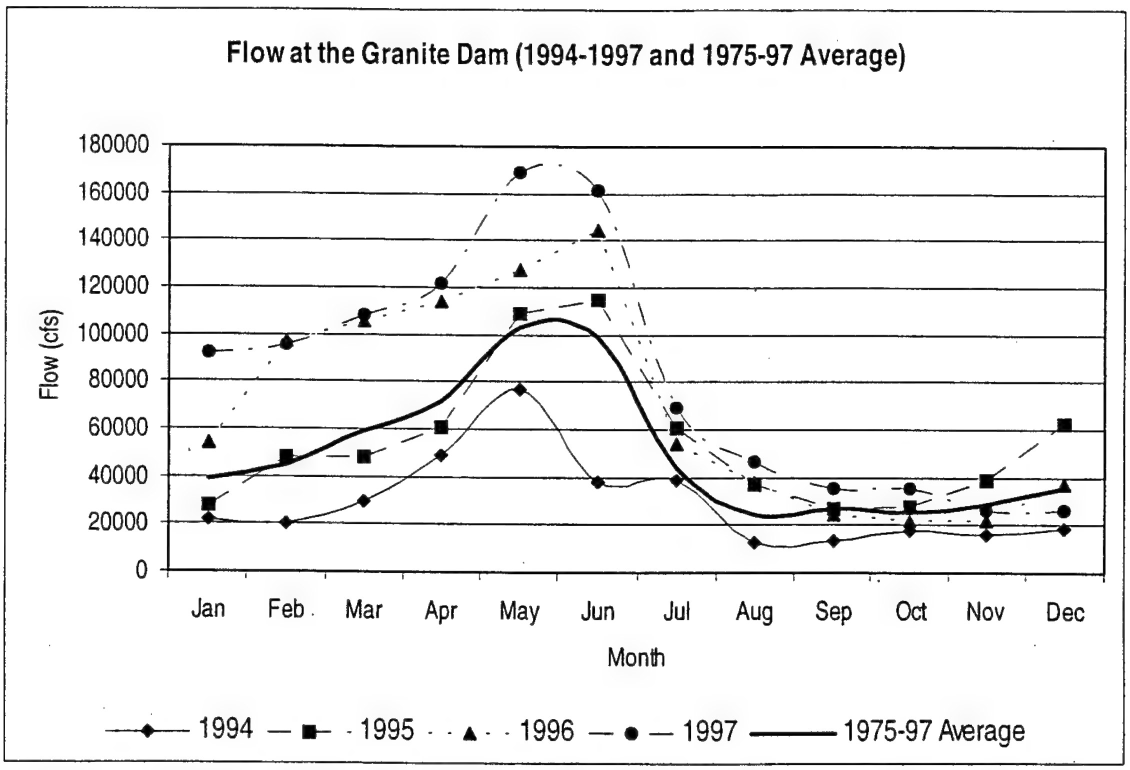

Figure 3-2. Monthly Mean Flow Data at Lower Granite Dam for the Years 1994-97

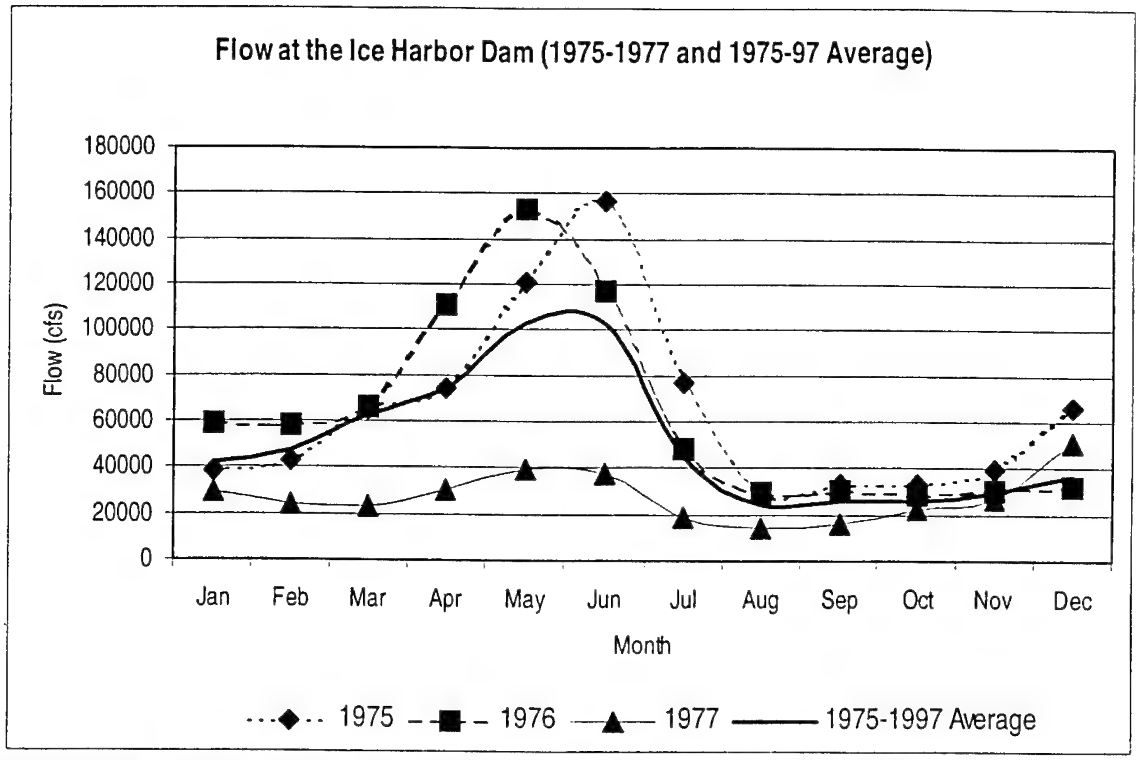

Figure 3-3. Monthly Mean Flow Data at Ice Harbor for the Years 1975-1977

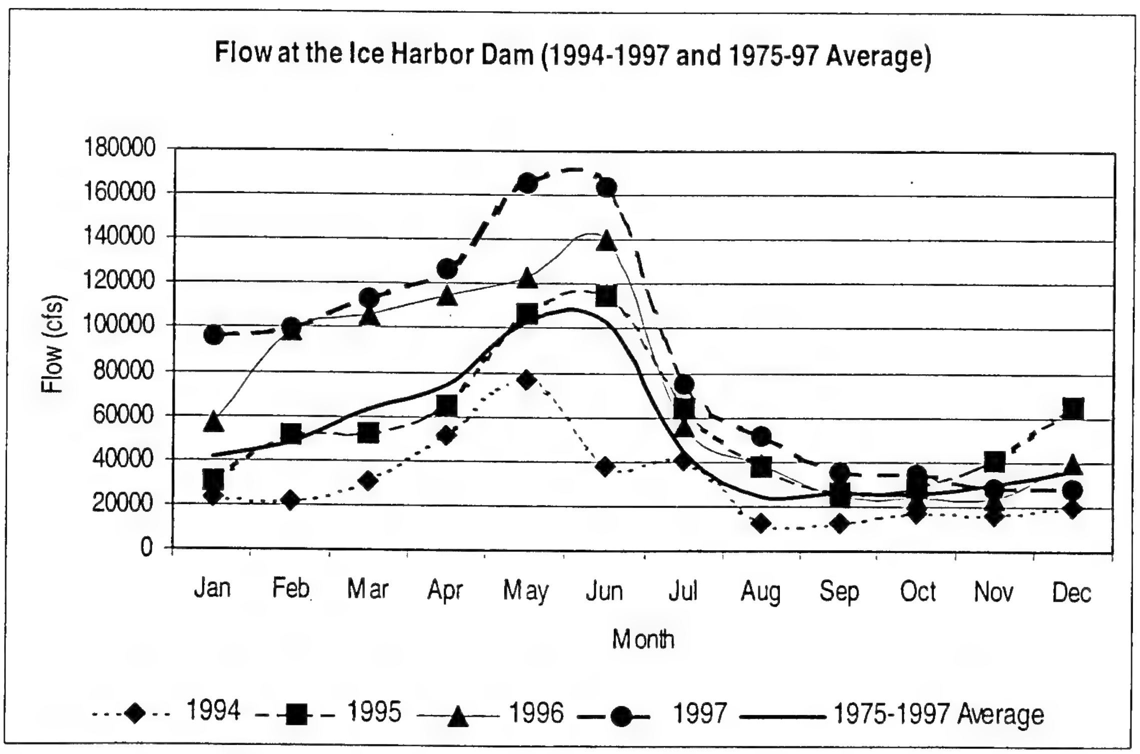

Figure 3-4. Monthly Mean Flow Data at Ice Harbor Dam for the Years 1994-1997

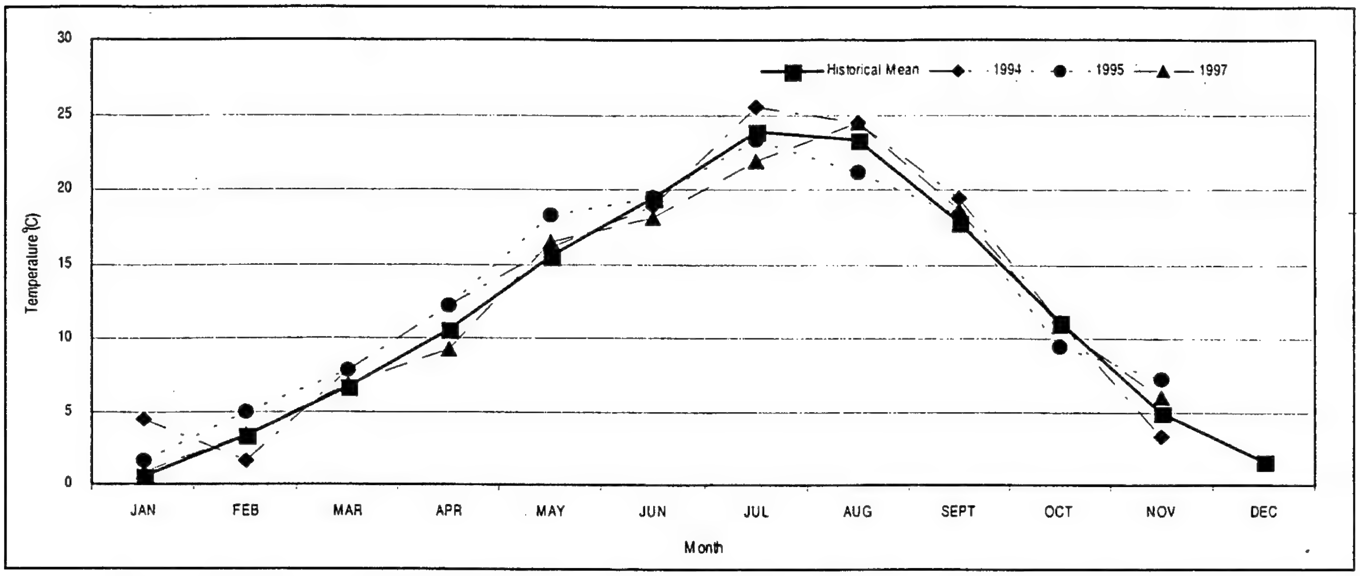

Figure 3-5. Comparison of Average Monthly Air Temperatures during 1994, 1995, and 1997 to the Historical Monthly Averages Recorded at the Nez Perce Weather Station in Lewiston, Idaho

temperatures were recorded. Both 1995 and 1997 had slightly below-normal mean monthly air temperatures in June and July. August was also cooler than normal in 1995, whereas in 1997 both August and September were slightly warmer than normal. Based on this comparison, the air temperatures in 1994 most likely had the greatest influence on peak water temperatures in the lower Snake River, followed by 1997, and then 1995.

3.2.4.1 Water Temperature

Water temperature is one of the more critical parameters affecting fish migration behavior during the April through September adult and juvenile salmonid migration periods. The optimal temperature range during the summer juvenile and adult migration period is generally recognized to be between 10 to 20°C (45 to 68°F) (BPA, 1995). The upper tolerance limit is considered to be 21°C (70°F), depending on whether fish have had sufficient time to acclimate to increasing temperatures. Water temperatures above 21°C (70°F) can have lethal effects on salmonid fishes if these high temperature waters cannot be avoided (BPA, 1995). However, salmon stocks have adapted certain life stages to higher seasonal temperatures in the southern part of their range. Historic water summer temperatures in the Snake River basin far exceeded the optimal ranges mentioned above. Adaptations included spring and summer chinook migrating into higher elevation tributaries to spawn so their young could rear where water temperatures were cooler. Snake River coho, sockeye, and steelhead adapted similar to the spring/summer chinook. Fall chinook spawned in the mainstem (usually near the mouth of major tributaries), about 95 percent of them upstream from the lower Snake River. Their life history was likely adjusted in avoidance of hot summer water temperatures in the lower Snake River by migrating before the heat of the summer when shoreline rearing areas heated up. Juvenile fall chinook from above Hells Canyon probably reached the lower Snake River before peak hot temperatures in the summer. Juvenile fall chinook from Hells Canyon,

the lower Clearwater River, and the lower Snake River probably moved through the lower Snake River to rear in the slightly cooler waters of the lower Columbia River (now McNary, John Day, The Dalles, and Bonneville Reservoirs) if they had not experienced a sufficient growth period in the middle or upper Snake River.

Water temperatures in the lower Snake River are relatively cool in May and June during the peak flow and snowmelt period, with typical readings ranging from 10 to 14°C (50 to 57°F) (Figures 3-6, 3-7, and 3-8). By mid- to-late July, however, temperatures usually warm up to 22°C to 24°C (71.6 to 75.2°F) and remain above 20°C (68°F) until late September. The highest temperatures generally occur from August to mid-September (BPA, 1995). The typical post-impoundment seasonal pattern is shown in Figures 3-7 and 3-8, which illustrates the observed surface water (0.1-1.0 m) temperatures in the Lower Granite Reservoir for the years 1975-1977 and 1994 to 1997, respectively. The late-summer maximum temperatures observed during these two three-year periods is consistent with previous research using USGS data collected from 1938 to 1966, which suggests that the most significant effect of hydropower dam construction may be that the period of maximum temperatures has shifted from mid-July through August to mid-August through September (EPA and NMFS, 1971; BPA, 1995). This is based upon a comparison with temperature data collected prior to dam construction (1955-1958) in the lower Snake River, where maximum temperatures were frequently above 22°C (72°F) from mid-July to late August (FWPCA, 1967). Similarly surface water temperature data (1 m depth) collected at SNR-107, prior to construction of the Lower Granite Dam, reached peak temperatures in excess of 22° C between mid-July and late-August (Figure 3-6).

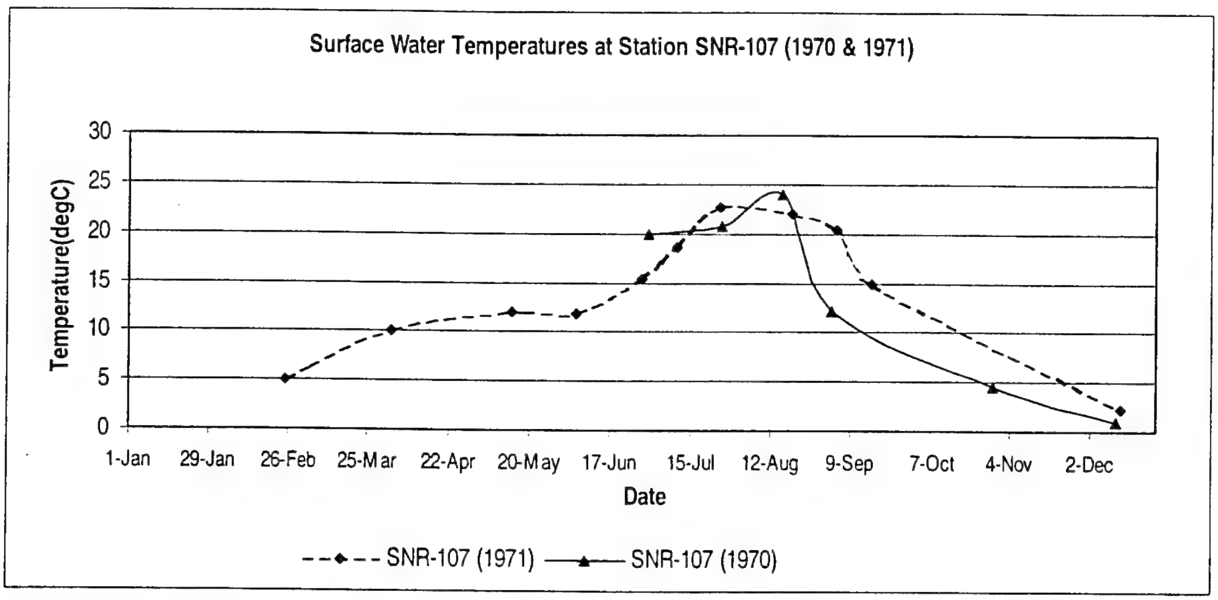

Figure 3-6. Seasonal Surface Water Temperature Data Collected prior to Construction of the Lower Granite Dam (1970 & 1971) at SNR-107

Since each of the Corps dams became operational, the Corps has recorded daily water temperatures passing through the dams and reported that information with adult fish count information. The fishery agencies and Corps agreed years ago that the scroll case water temperatures would be the best representation of the average water temperature the fish would experience. The scroll case draws water from all depths of the reservoir, and passes that water over the turbine blades to drive the generators of the dam.

Maximum scroll case temperatures are represented in Table 3-2 for Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dam. There is a break in the data for Little Goose Dam from 1982 through 1990 when adult fish were not counted. Also shown in the table is the period of time that the water temperature exceeded the state temperature standard (20°C or 68°F). These data are graphically illustrated in Figures 3-7, 3-8, 3-9, and 3-10.

The general impression from these data is that maximum water temperatures have gone down since the reservoirs were created (Figures 3-7 through 3-10). The highest maximum temperatures (24.4°C or 76°F) generally occurred within the first year or two after the reservoir was created at all of the facilities except Lower Granite where in 1981 and 1990, 78°F and 77°F temperatures were recorded. Days when the maximum exceeded the standard started at Ice Harbor Dam as early as the 4th of July and as late as the middle of August. Temperatures exceeded the standard as late as the end of September. The duration of the exceedance appears to be more a function of the annual flow volume influenced by the duration of hot summer weather rather than related to water warming in the reservoirs.

When considering the temperature of water in the Clearwater and the Hells Canyon reach of the Snake River following the first day of exceedance downstream, it is readily apparent that warm water flows into the reservoirs from upstream and works its way downstream. Similarly, the last day of exceedance works its way downstream when cooler water from the tributaries enters Lower Granite Reservoir and works its way downstream.

Since 1991, cool water releases from Dworshak Reservoir have had a substantial impact on the maximum temperature and days of exceedance. From 1992 through 1998, the maximum temperature at Lower Granite Dam ranged from 68 to 72°F whereas the average temperature since the dam began operating was 73.4°F, reaching a high of 77°F in 1990. The number of days of exceedance from 1992 to 1998 ranged from 0 to 36, whereas the average since the dam began operating was 44.3 days, ranging from 25 to 85 days.

Figures 3-11 and 3-12 illustrate that peak surface water temperatures at Lower Granite Dam (Station SNR-108) during the sampled years were correlated to differences in average flow rates. For example, in 1977 average flow rates at Lower Granite Dam were below the historical average for most of the year (Figure 3-1). In contrast, the surface water temperatures observed were consistently higher than those observed in the high flow years of 1975 and 1976, and reached a peak of nearly 25°C (Figure 3-11). Conversely, the average monthly flow rate in August 1997 was approximately 150 percent greater than the average monthly flow rate in August 1994. The peak occurred between July and September, when observed temperatures were generally lower than those observed in 1994. Surface water temperature data collected in Ice Harbor Reservoir showed a similar relationship to flow, with higher temperatures being observed during the low-flow years of 1977 and 1994 (Figures 3-13 and 3-14).

Table 3-2. Maximum Water Temperatures at Corps Dams

Year	Ice Harbor					Lower Monumental					Little Goose					Lower Granite				
	Degrees F	Degrees C	Days over 68	First Day	Last Day	Degrees F	Degrees C	Days over 68	First Day	Last Day	Degrees F	Degrees C	Days over 68	First Day	Last Day	Degrees F	Degrees C	Days over 68	First Day	Last Day
62	76	24.44	60	16 July	13 Sept.															
63	76	24.44	71	13 July	21 Sept.															
64	72	22.22	47	15 July	30 Aug.															
65	75	23.89	42	21 July	31 Aug.															
66	75	23.89	60	14 July	11 Sept.															
67	76	24.44	75	12 July	30 Sept.															
68	75	23.89	54	9 July	9 Sept.															
69	73	22.78	57	19 July	13 Sept.															
70	73	22.78	61	13 July	11 Sept.	74	23.33	53	10 July	3 Sept.										
71	74	23.33	54	25 July	16 Sept.	75	23.89	54	22 July	13 Sept.	76	24.44	54	18 July	9 Sept.					
72	73	22.78	36	9 Aug.	13 Sept.	73	22.78	39	5 Aug.	13 Sept.	73	22.78	42	1 Aug.	12 Sept.					
73	72	22.22	42	22 July	7 Sept.	72	22.22	43	25 July	5 Sept.	74	23.33	46	13 July	2 Sept.					
74	72	22.22	46	30 July	13 Sept.	71	21.67	48	27 July	12 Sept.	74	23.33	51	23 July	14 Sept.					
75	71	21.67	29	28 July	31 Aug.	70	21.11	33	31 July	1 Sept.	70	21.11	37	25 July	30 Aug.	76	24.44	35	21 July	25 Aug.
76	71	21.67	44	30 July	16 Sept.	70	21.11	41	7 Aug.	7' Sept.	71	21.67	38	28 July	13 Sept.	72	22.22	51	18 July	10 Sept.
77	73	22.78	43	27 July	7 Sept.	71	21.67	35	27 July	11 Sept.	72	22.22	26	10 Aug.	4 Sept.	76	24.44	49	28 June	5 Sept.
78	72	22.22	28	3 Aug.	8 Sept.	72	22.22	38	30 July	5 Sept.	72	22.22	29	30 July	27 Aug.	75	23.89	35	20 July	10 Sept.
79	73	22.78	74	19 July	30 Sept.	73	22.78	67	24 July	28 Sept.	74	23.33	64	22 July	24 Sept.	74	23.33	59	17 July	17 Sept.
80	72	22.22	48	31 July	16 Sept.	71	21.67	40	24 July	2 Sept.	73	22.78	43	22 July	3 Sept.	74	23.33	39	21 July	28 Aug.
81	73	22.78	55	29 July	30 Sept.	74	23.33	55	1 Aug.	24 Sept.	73	22.78	61	23 July	21 Sept.	78	25.56	64	17 July	18 Sept.
82	72	22.22	35	14 Aug.	17 Sept.	72	22.22	52	26 July	15 Sept.	73	22.78	49	29 July	15 Sept.	74	23.33	46	26 July	12 Sept.
83	73	22.78	40	8 Aug.	16 Sept.	74	23.33	42	5 Aug.	17 Sept.			No data.	---	---	74	23.33	41	30 July	9 Sept.
84	73	22.78	60	20 July	17 Sept.	73	22.78	49	26 July	12 Sept.			No data.	---	---	74	23.33	46	23-Jul	6 Sept.
85	75	23.89	51	17 July	5 Sept.	73	22.78	54	10 July	1 Sept.			No data.	---	---	74	23.33	49	7 July	28 Aug.
86	75	23.89	73	9 July	19 Sept.	74	23.33	52	9 July	20 Sept.			No data.	---	---	74	23.33	62	30 June	12 Sept.
87	72	22.22	81	4 July	22 Sept.	71	21.67	71	12 July	20 Sept.			No data.	---	---	73	22.78	74	26 June	15 Sept.
88	72	22.22	53	27 July	17 Sept.	72	22.22	50	25 July	12 Sept.			No data.	---	---	73	22.78	85	25 June	20 Sept.
89	71	21.67	50	25 July	12 Sept.	71	21.67	49	25 July	11 Sept.			No data.	---	---	74	23.33	47	13 July	28 Aug.
90	73	22.78	70	24 July	1 Oct.	73	22.78	59	30 July	26 Sept.			No data.	---	---	77	25.00	77	3 July	18 Sept.
91	74	23.33	49	1 Aug	18 Sept.	74	23.33	44	5 Aug.	17 Sept.	76	24.44	55	23 July	16 Sept.	76	24.44	55	12 July	12 Sept.
92	71	21.67	43	16 July	10 Sept.	71	21.67	50	10 July	13 Sept.	72	22.22	49	4 July	10 Sept.	72	22.22	25	* 1 July	* 28 Aug.
93	68	20.00	0	---	---	68	20.00	0	---	---	72	22.22	40	8 Aug.	29 Sept.	69	20.56	8	18 Aug.	5 Sept.
94	70	21.11	18	16 July	5 Aug.	71	21.67	30	* 13 July	* 20 Sept.	72	22.22	28	* 8 July	* 2 Oct.	73	22.78	32	* 17 July	* 11 Sept.
95	70	21.11	18	25 July	11 Aug.	70	21.11	23	19 July	10 Aug.	72	22.22	26	16 July	9 Aug.	68	20.00	0	---	---
96	70	21.11	41	23 July	1 Sept.	70	21.11	41	20 July	29 Aug.	71	21.67	53	12 July	2 Sept.	70	21.11	23	22 July	16 Aug.
97	71	21.67	44	21 July	5 Sept.	71	21.67	28	3 Aug.	8 Sept.	71	21.67	57	1 Sept.	26 Sept.	71	21.67	26	21 Aug.	17 Sept.
98	73	22.78	52	* 19 July	* 8 Oct.	73	22.78	75	17 July	30 Sept.	72	22.22	82	12 July	1 Oct.	70	21.11	36	* 10 July	* 25 Sept.

NOTES:
Highest temperatures usually occur in August at all dams, but with unseasonably warm weather, may occur in late July or with prolonged hot weather, in September.
Blanks for Little Goose (1983-90) are for years when data was not reported.

* Temperatures over 68 degrees F occurred between 2 periods.

LM, 1994 13 July-21 July, 9 days over 68 F
31 Aug.-20 Sept., 21 days over 68 F

LGO, 1994 8 July-4 Aug.; 28 days over 68 F
24 Aug.-2 Oct., 40 days over 68 F

LWG, 1992 1 July, 1 day over 68 F
5 Aug.-28 Aug., 25 days over 68 F
13 Aug.-11 Sept., 29 days over 68 F

LWG, 1998 10 July-July 22, 5 days over 68 F
7 Aug.-25 Aug., 7 days over 68 F
2 Sept.-25 Sept., 24 days over 68 F

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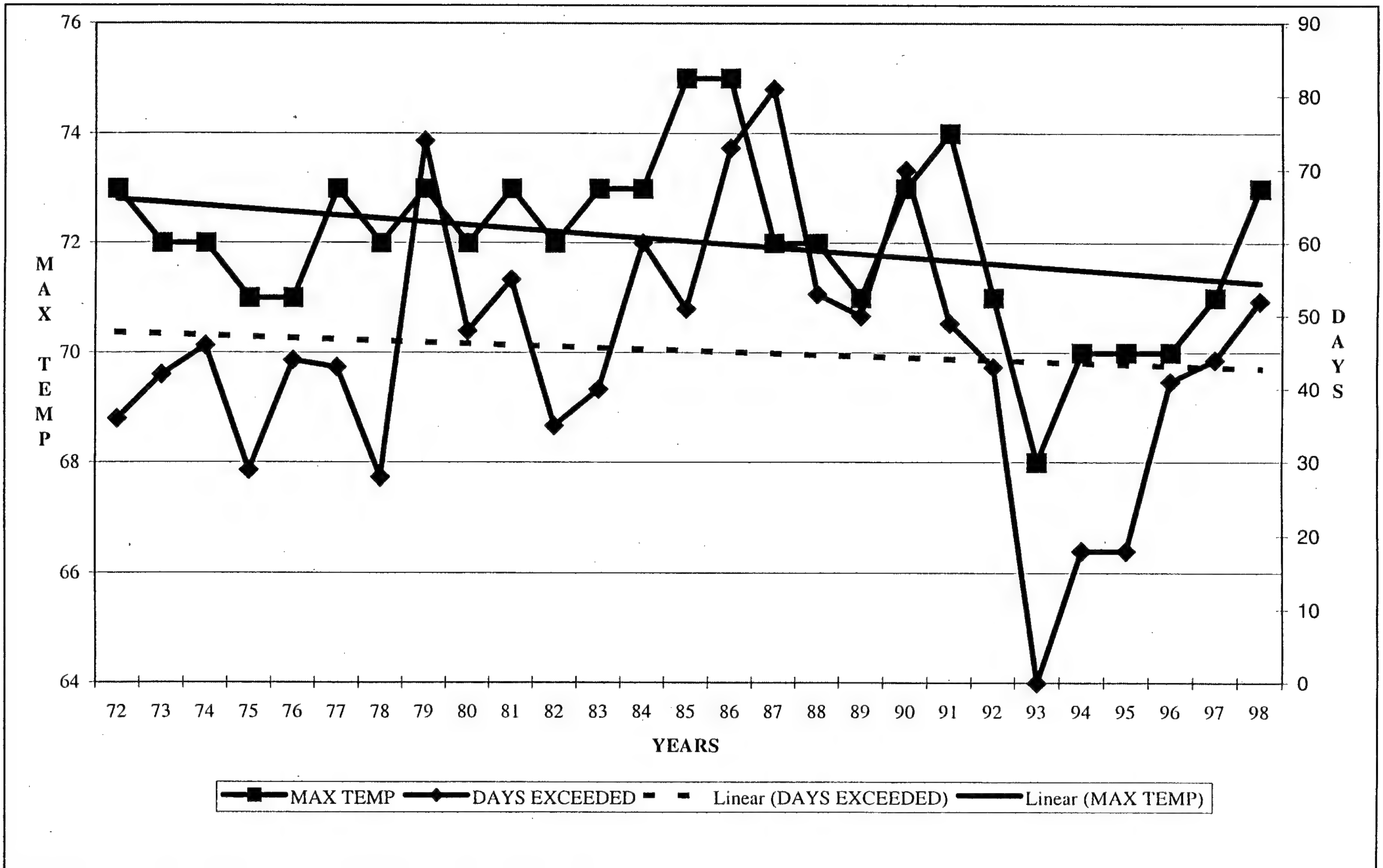

Figure 3-7. Days Exceeding 20 Degrees C - Ice Harbor Dam

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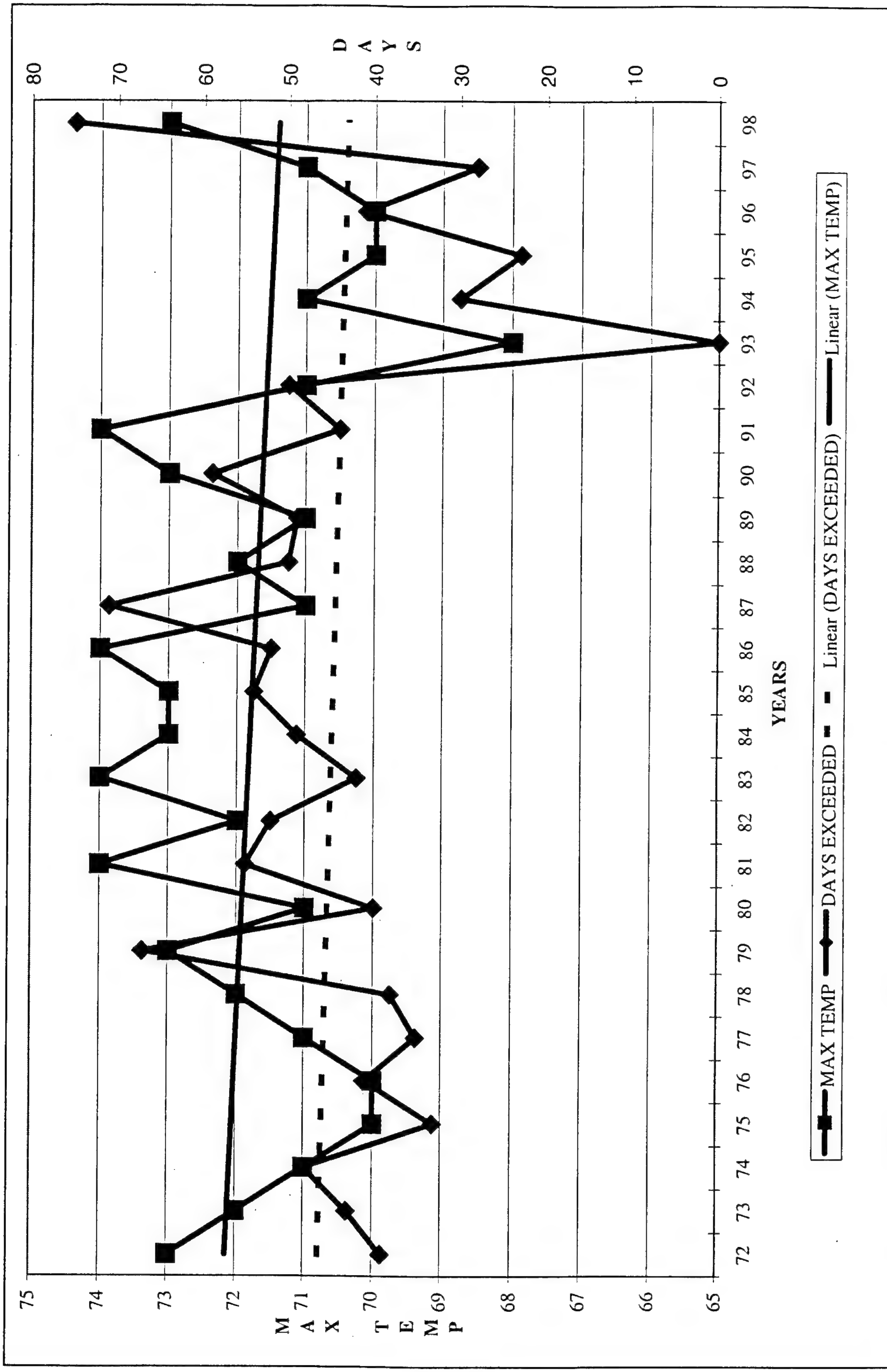

Figure 3-8. Days Exceeding 20 Degrees C - Lower Monumental Dam

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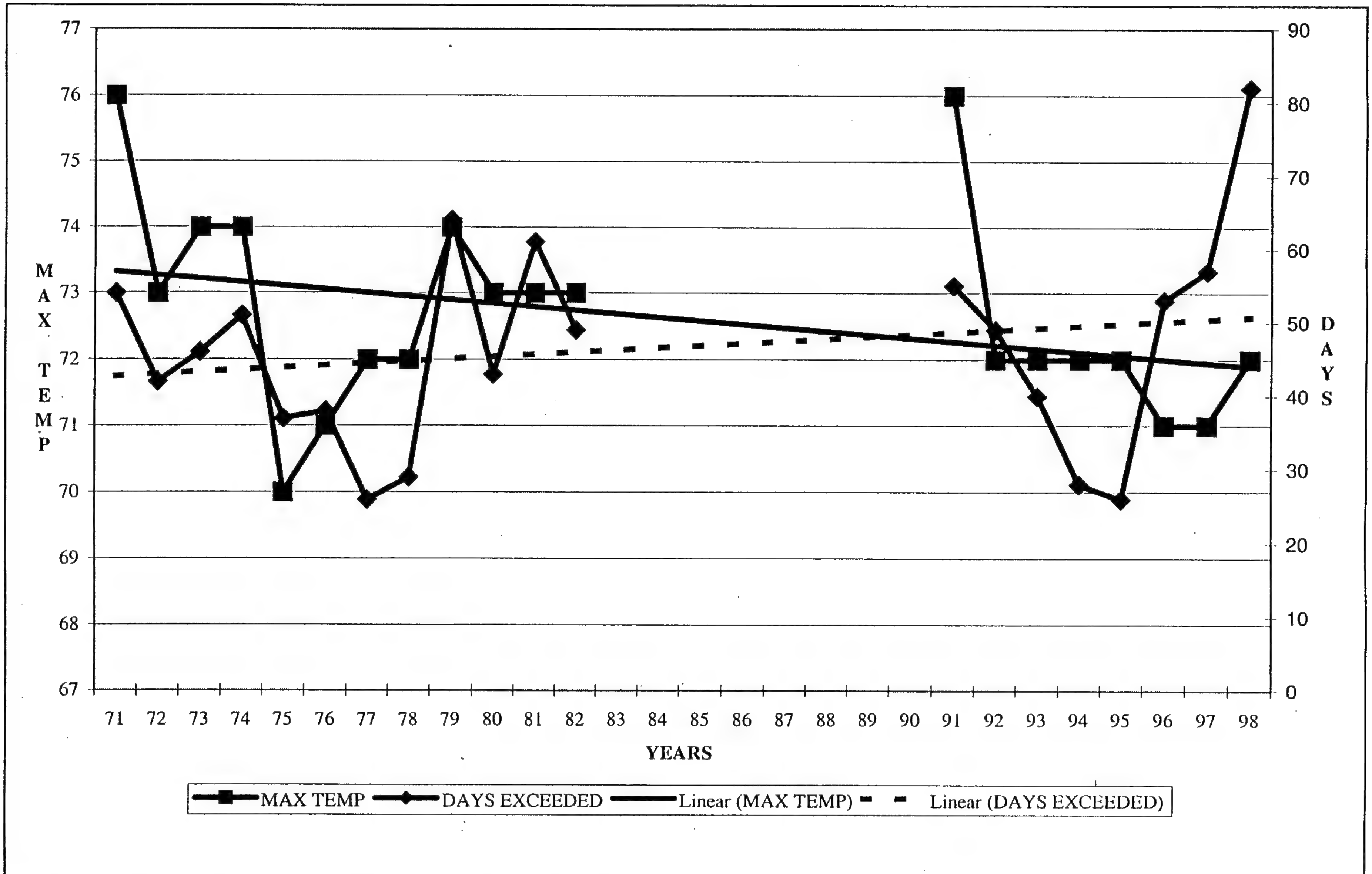

Figure 3-9. Days Exceeding 20 Degrees C – Little Goose Dam

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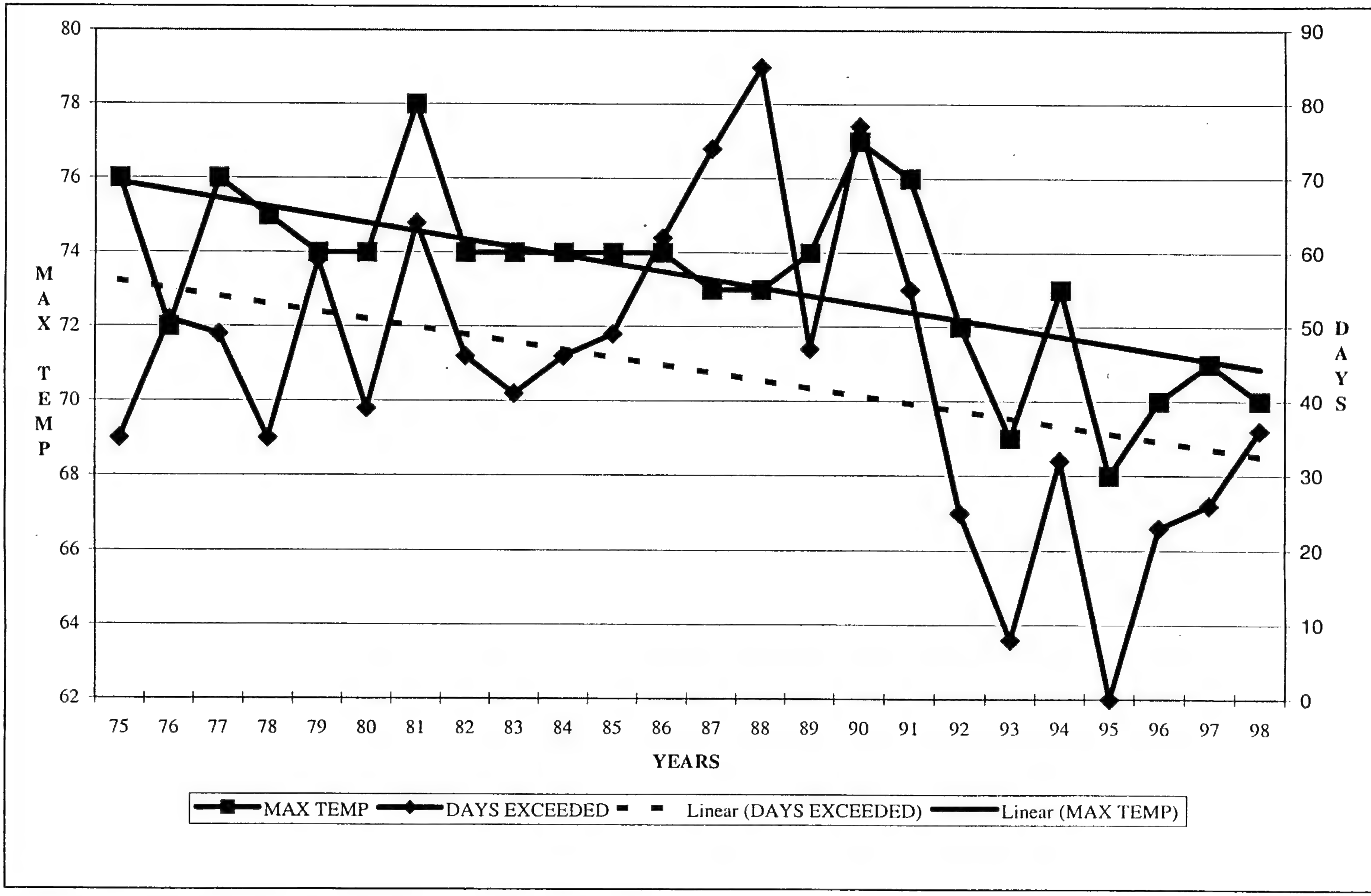

Figure 3-10. Days Exceeding 20 Degrees C – Lower Granite Dam

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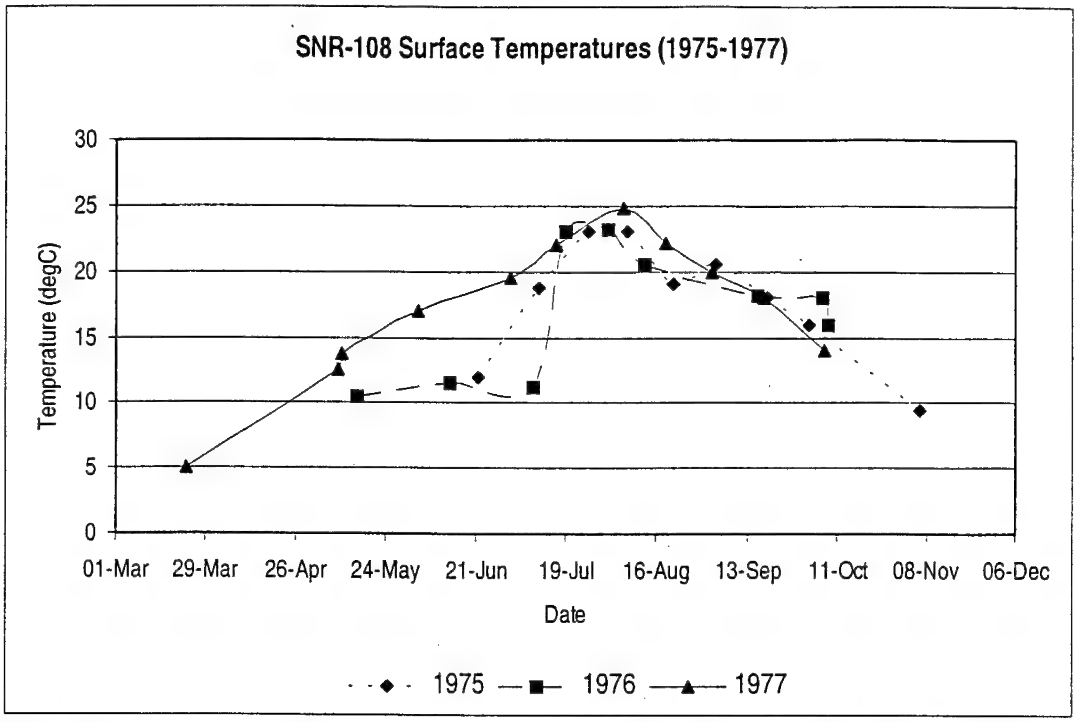


Figure 3-11. Surface Water Temperature Data Recorded at Lower Granite Station SNR-108 for the Years 1975-77

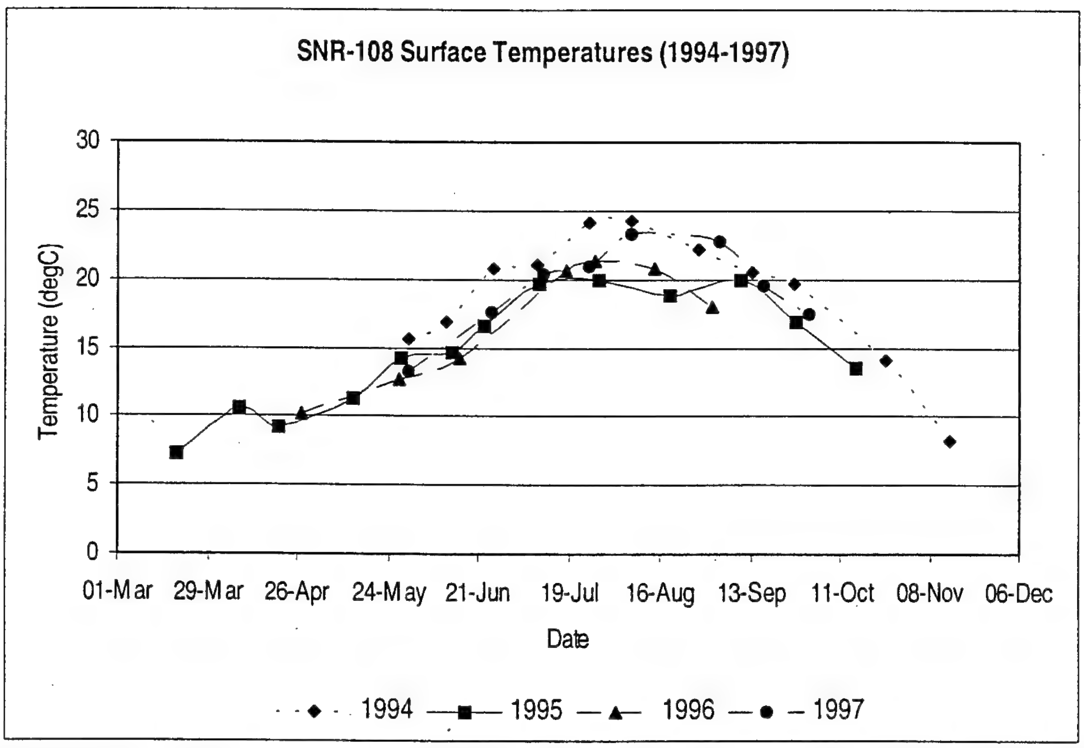


Figure 3-12. Surface Water Temperature Data Recorded at Lower Granite Station SNR-108 for the Years 1994-97

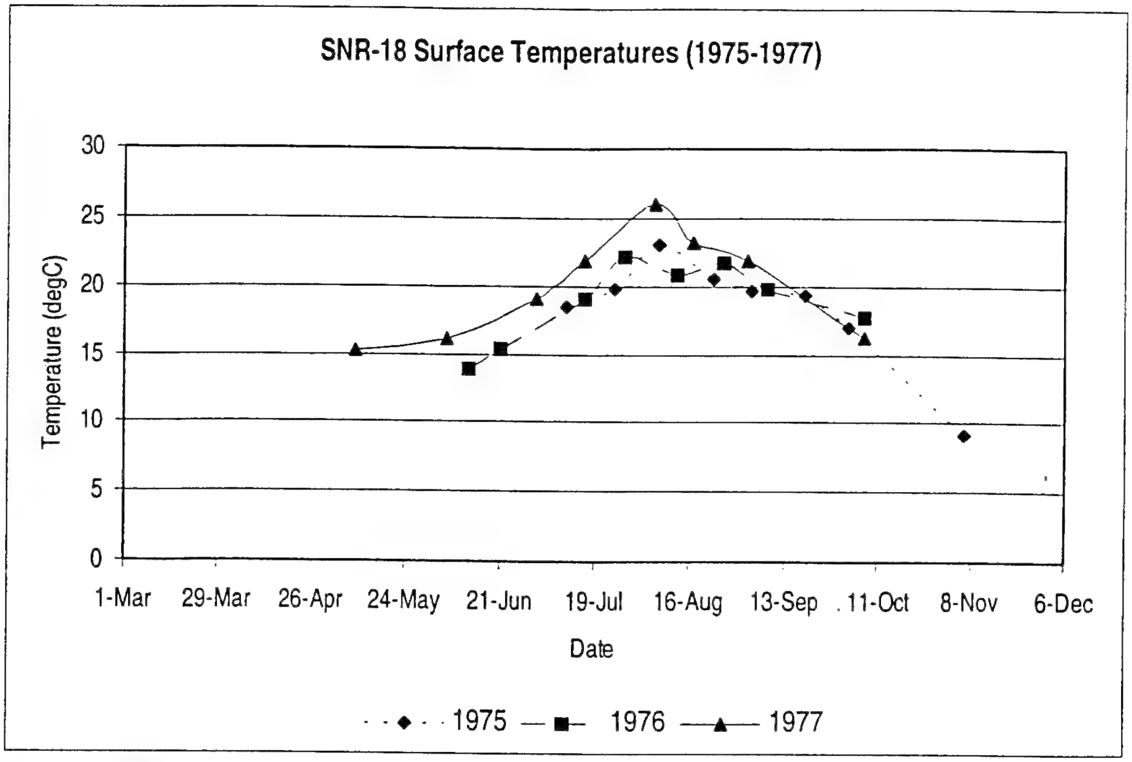


Figure 3-13. Surface Water Temperature Data Recorded at Station SNR-18 for the Years 1975-1977

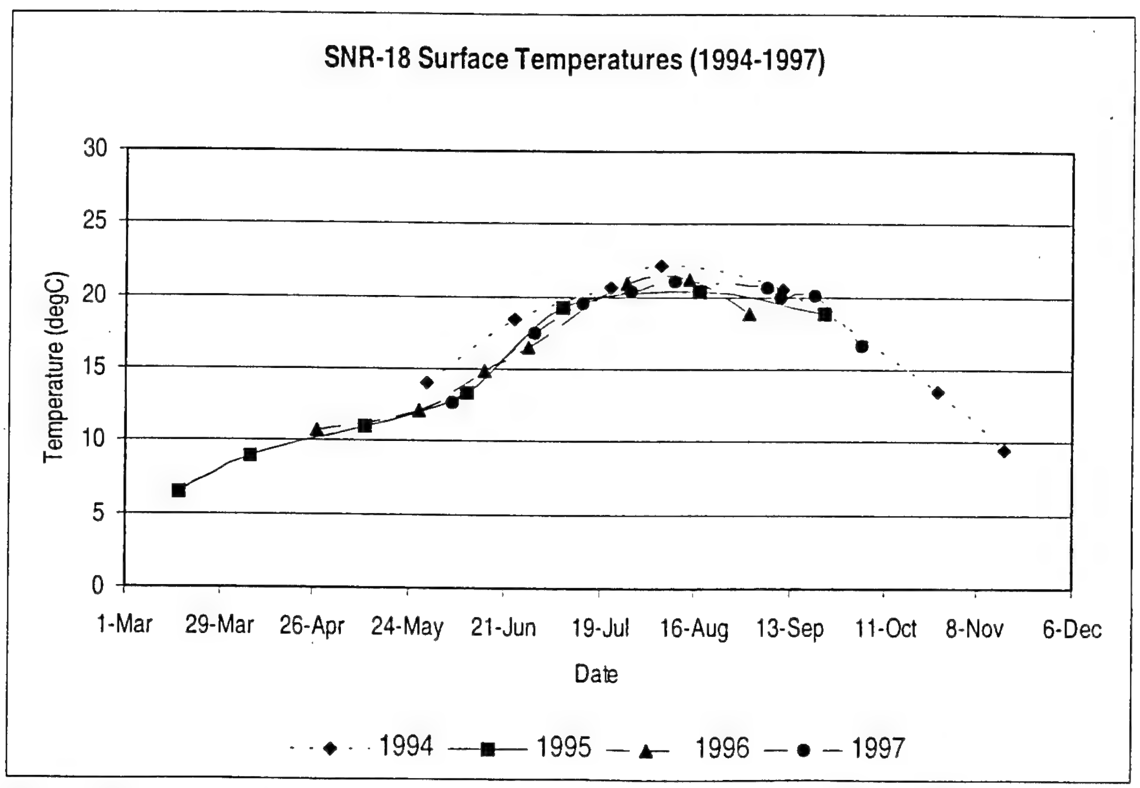


Figure 3-14. Surface Water Temperature Data Recorded at Station SNR-18 for the Years 1994-1997

However, peak water temperatures also appear to be influenced by other factors including ambient air temperatures, solar radiation, and percentage of total discharge contributed from Dworshak Reservoir. The influence of air temperature on peak water temperature is notable for 1995, when water temperatures reached a peak value that was lower than those observed in both 1994 (when relatively large releases from Dworshak Reservoir were initiated) and 1997 (a high flow rate year). This lower peak temperature observed in 1995 is likely attributable to the cooler-than-normal mean monthly air temperatures observed between June and late September (see Figure 3-5).

Flow rates also seem to affect the duration of elevated water temperatures. The slower flow rates and increased surface area of water within the impoundments can cause surface waters to reach higher maximum temperatures and then cool down more slowly in the fall (BPA, 1995). In reviewing the data, 1977 and 1994 clearly stand out as having two to three months with surface temperatures above 20°C (68°F), as compared to less than two months observed in other years. In addition, it took at least a week longer in 1994 for the water temperatures at SNR-108 to drop back below 20°C (68°F). This longer period of elevated temperatures or the delay in cooling would be expected to adversely affect fish migration patterns.

Figure 3-15 presents a comparison of the observed surface water temperatures (1.0 m depth) in 1997 at selected stations throughout the project area. In the Columbia River, the maximum temperatures in the lower end of the McNary Reservoir at Station CLR-295 reached 21.4°C (71.3°F) during the first week of August and remained unchanged through mid-August, held at 20°C (68°F) until September 1, then dropped back down to 16°C (58.8°F) by mid-October. At station CLR-326, upstream of the Snake River confluence, peak temperatures remained below 20°C (68°F) throughout the sampling period. Surface water temperature data collected from various stations along the lower Snake River during the low-flow year of 1994 indicates that a higher maximum temperature was reached in Lower Granite reservoir (24.3 C) and upstream at SNR-140 (23.8 C) than during 1997 (Figure 3-16). Previous research has indicated that thermal stratification in the lower Snake River impoundments does not appear to occur to any significant extent (Funk et al., 1985). However, in 1997, a high flow year, the maximum temperature difference between surface and bottom waters was 4.7°C (8.2°F). This was observed on August 11 at Station SNR-108 in the Lower Granite Reservoir, the deepest reservoir station with the largest temperature gradient between zero and 10 m depth (Figure 3-17). Temperature profile data from 1994 (Figure 3-18), a low-flow year, depict a larger difference between surface temperatures and temperatures at depth following 28 days of large water releases from Dworshak Reservoir. The reservoir does not stratify, but may grade due to the sinking of more dense cooler water. This is most apparent in Lower Granite Reservoir (e.g., SNR-108 and SNR-129) where the difference between surface temperatures and temperatures at 35 meters depth approached 9° C.

1977 was a severe drought year. The flow records since 1938 show it to be the lowest year on record. Historically, the maximum temperature difference reported for surface and bottom waters was 4.7°C (8.2°F), measured in 1977 at SNR-108 (a high-flow year), and more typical differences are around 2.0°C (4°F) (Funk et al., 1985). It is noteworthy that both the 1997 and 1994 data were collected during a period of large water releases from Dworshak Reservoir (20.4 kcfs in 1997 and 25+ kcfs in 1994). Thus, the significant inputs of cooler water from Dworshak Reservoir, and the higher than normal river flows may have resulted in the larger than normal temperature gradients that were observed at depth. The remaining reservoir stations generally had a difference of less than a 2 to 3°C (3.6 to 5.4°F) throughout the water column (Normandeau, 1999a). An increase in thermal

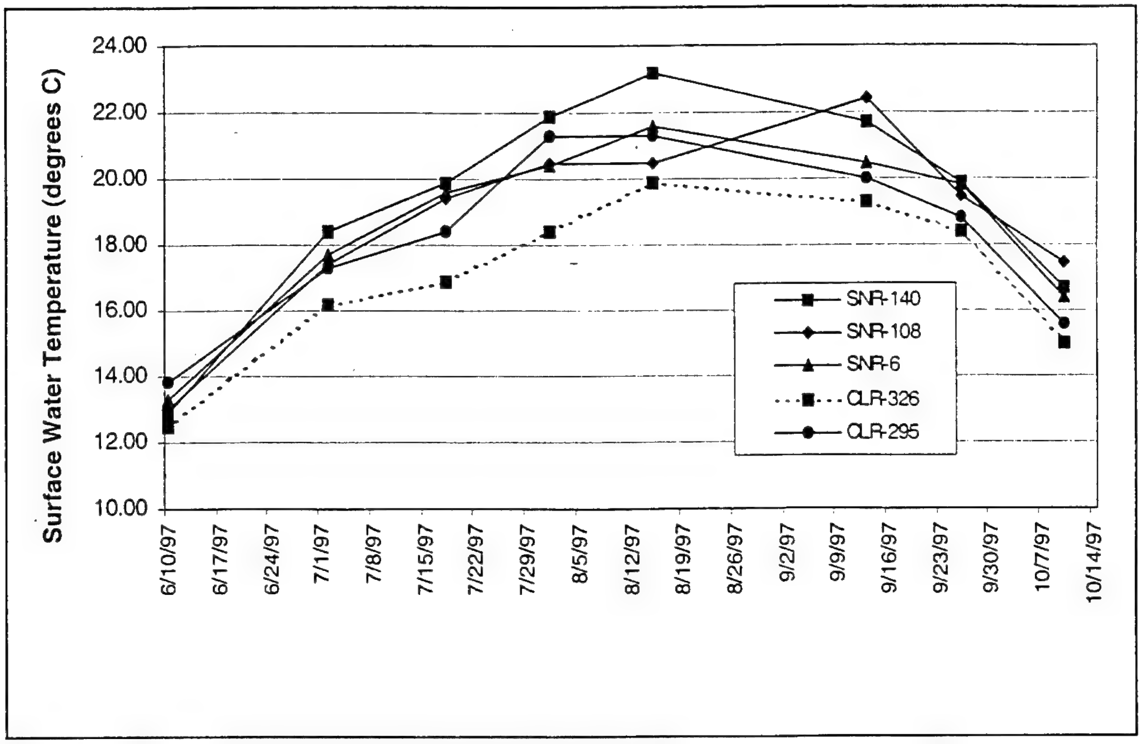


Figure 3-15. Surface Water Temperature Data Measured in 1997 at Selected Sampling Stations throughout the Project Area

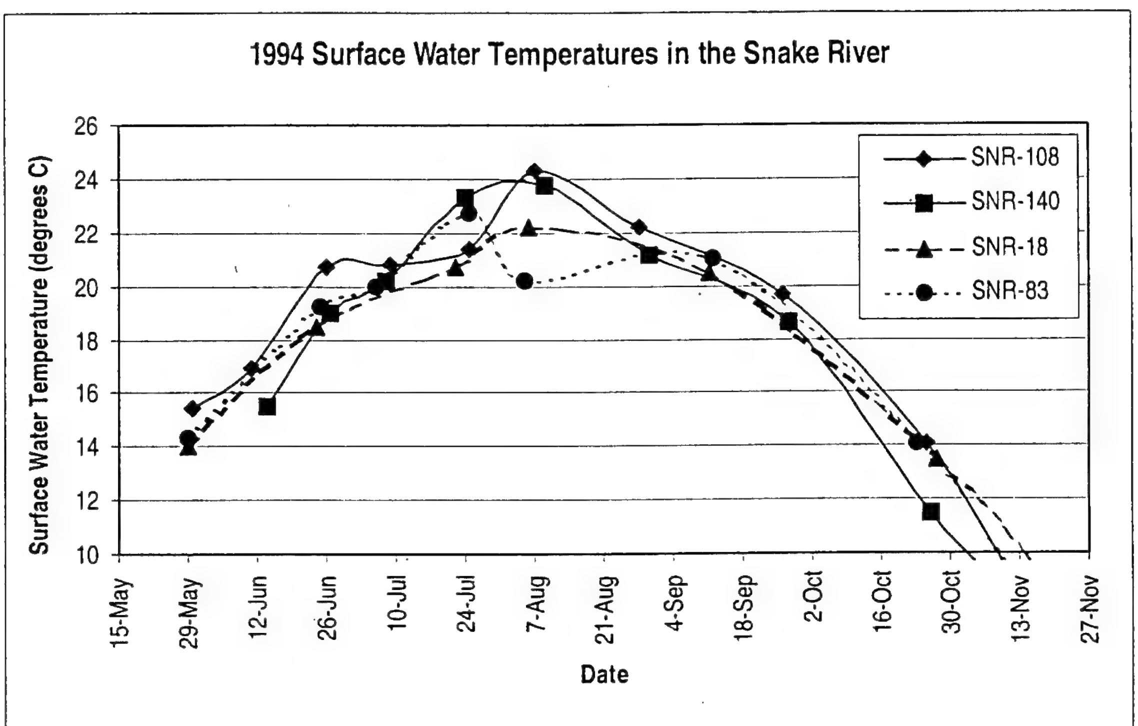


Figure 3-16. Surface Water Temperature Data Measured in 1994 at Selected Sampling Stations

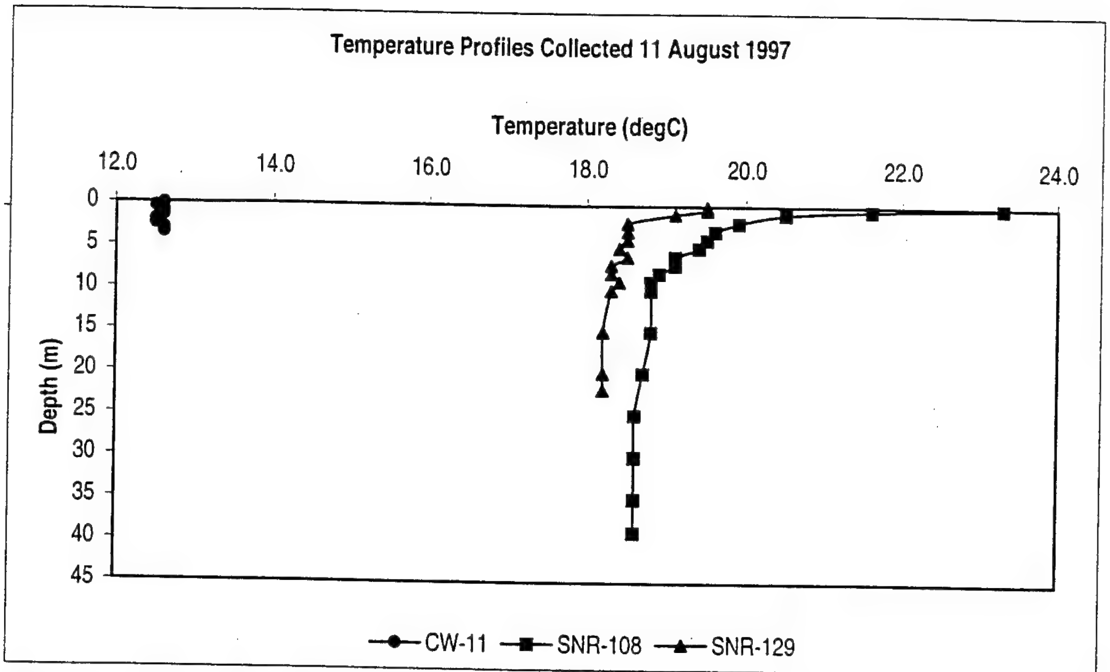


Figure 3-17. Temperature Profile for Three Stations Downstream of the Dworshak Dam

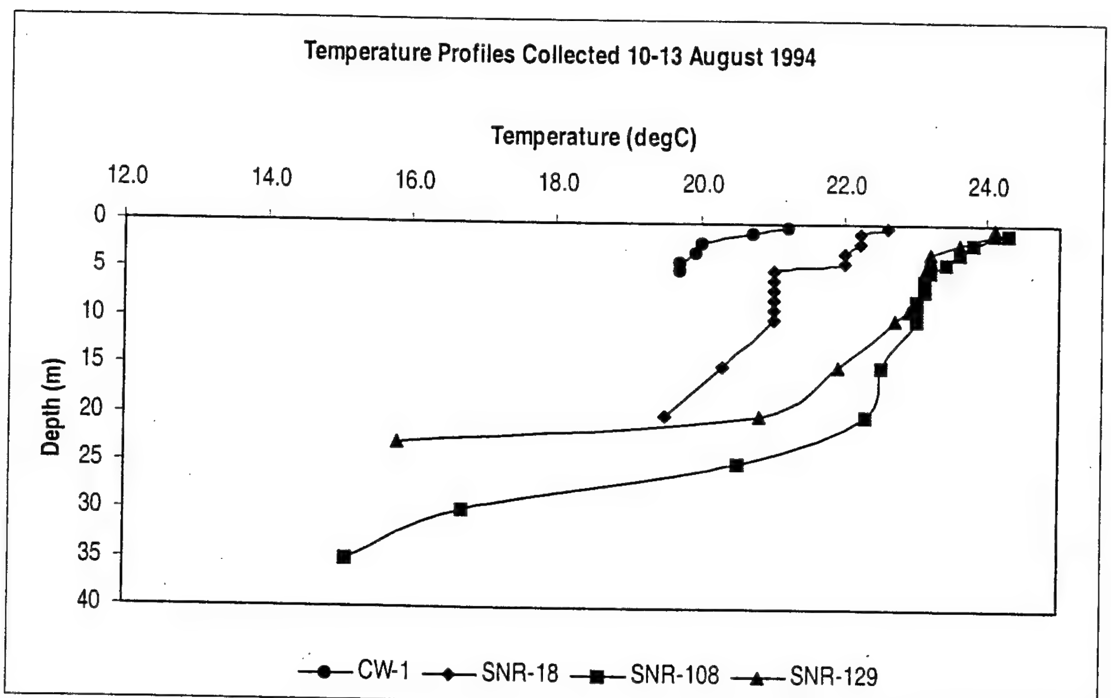


Figure 3-18. Temperature Profiles from Four Stations in August of 1994

gradation could lead to lower dissolved oxygen levels in the deeper waters and increased nutrient releases into the water column from bottom sediments if anoxic conditions were to occur with prolonged gradation or the formation of stratification.

In 1994, releases from Dworshak Dam began early in July, reaching a maximum of 25 kcfs by mid-month, and were completed by the end of the month. During this time period, the median flow contribution from the Clearwater River accounted for 54 percent of the total inflow to Lower Granite Reservoir and as much as 65 percent of the total flow on one occasion. Based on temperature data collected from D.H. Bennett from the UI, these cold water releases resulted in a 5°C (11°F) drop in water temperature in July in Lower Granite Reservoir at a depth of 6 meters (See Figure 3-19). Differences in surface temperature data collected in Ice Harbor Reservoir (SNR-18) before and after 28 days of releases from Dworshak Dam in 1994 were less pronounced, with a maximum difference of 2.2°C (Figure 3-20). Similarly, Karr et al. (1997) noted a decrease in temperature at mid-depth from 5.3 C (9.5 F) at Lower Granite Dam to 2.4 C (4.4 F) at the Ice Harbor Dam. Temperature reductions were noted throughout much of the water column, although a steep gradient was present near the surface (Karr et al., 1997). In 1995, releases began in mid-July and continued to the end of August. The maximum release rate was 13.8 kcfs and accounted for about 45 percent of the downstream flows, and a temperature drop of 3° C (5.5° F) at the Lower Granite Dam (Karr et al., 1997). A similar release pattern was conducted in 1997 as well. Under these flow release conditions, downstream temperatures were apparently lowered by up to 10°C (50°F) in the Clearwater River and only by up to 1 to 2°C (2 to 4°F) in Lower Granite Reservoir. The impact on water temperature is delayed, and reduced with increasing distance downstream from Dworshak Dam (Karr et al., 1997; Normandeau, 1999a).

3.2.4.2 Dissolved Oxygen

In contrast to water temperatures, the highest dissolved oxygen (DO) concentrations are typically observed during spring runoff and tend to decline with increasing temperature. The USGS data going back to 1975 indicate that low minimum DO levels of 2.3, 4.8, and 5.8 mg/L have been recorded below Lower Granite Dam (RM 106.5), in the Clearwater River (RM 11.6), and upstream at Weiser, ID, respectively.

Figure 3-21 presents a comparison of DO data throughout the project area for selected stations sampled in 1997. The values represent DO concentrations averaged over the entire water column. For the two Columbia River stations (CLR-326 and CLR-295), DO concentrations were consistently above 8.0 mg/L over the entire sampling period. The lowest reading was 8.1 mg/L in the bottom waters of the McNary Reservoir during the mid-September sampling event, which equals the 90 percent saturation level specified by the Oregon water quality standards. DO concentrations at all the stations were generally at their lowest levels during mid-September. During the early spill season, April through mid-July, DO levels are maintained by entrainment of air over spillways. As DG supersaturation occurs, DO concentrations are supplemented.

Figure 3-22 depicts seasonal DO concentrations of surface waters (1 m depth) collected before construction of the Lower Granite Dam (1970 and 1971) from SNR-107, and post-construction (1995, a normal flow year) from SNR-108. This data indicates that during a free-flowing state prior to construction of the dam, DO concentrations followed a similar seasonal pattern with higher concentrations during the spring and declining concentrations throughout the summer into the fall.

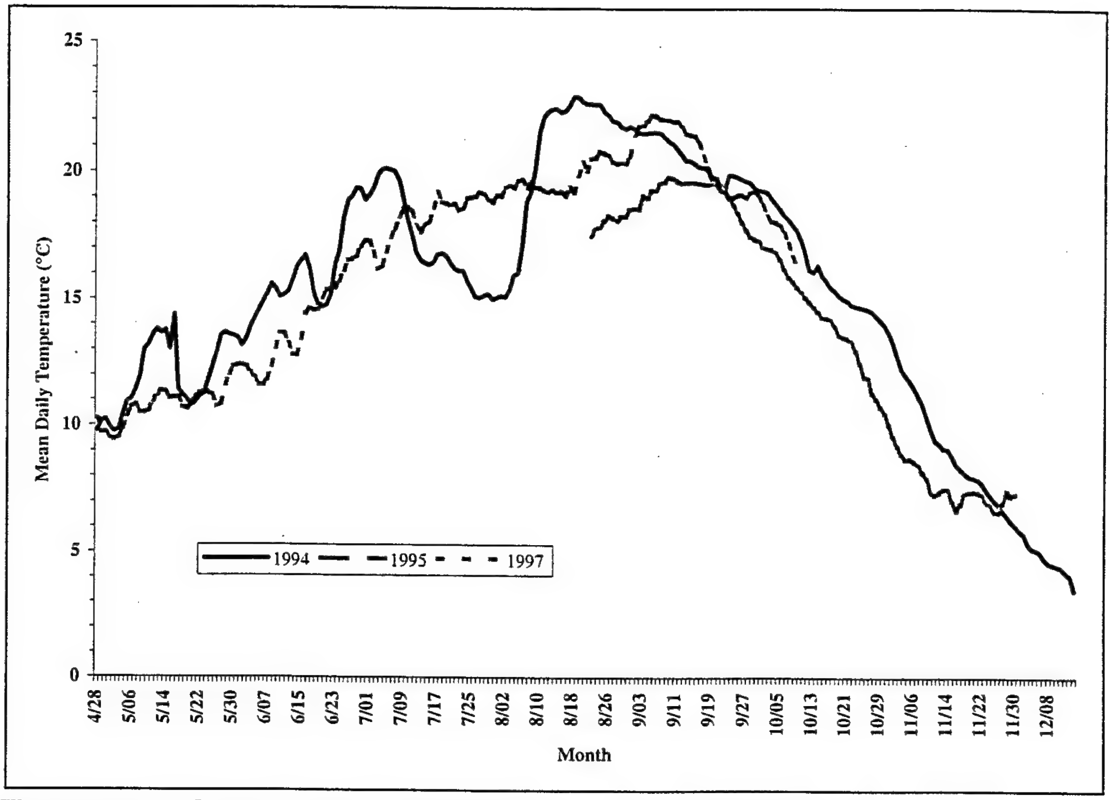


Figure 3-19. Surface Water Temperatures in Lower Granite Forebay

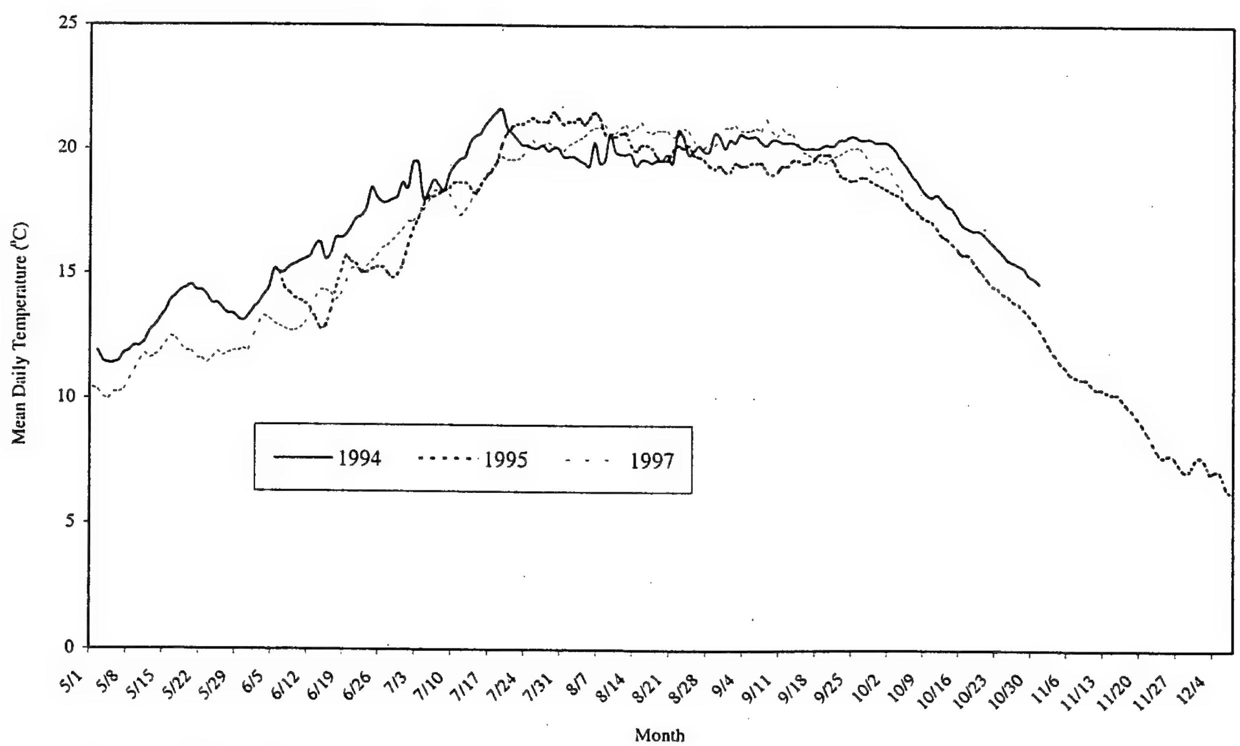


Figure 3-20. Surface Water Temperatures in Ice Harbor Reservoir (SNR-18) for the Years 1994-1997

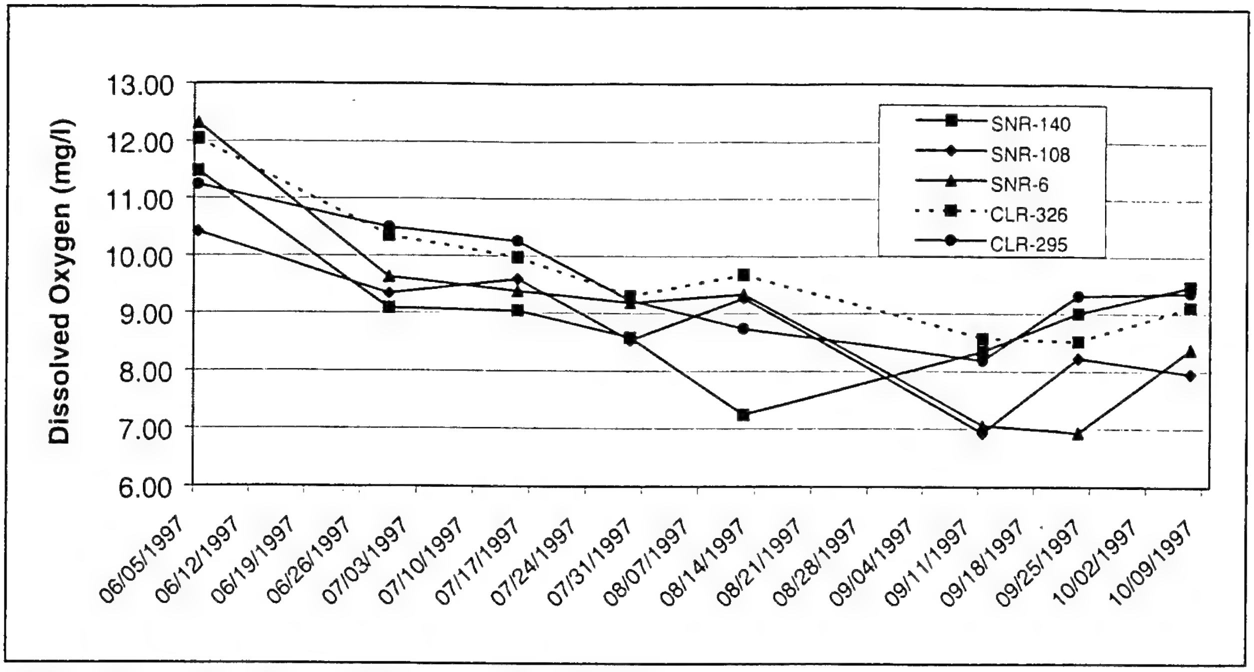


Figure 3-21. Dissolved Oxygen for Select Stations

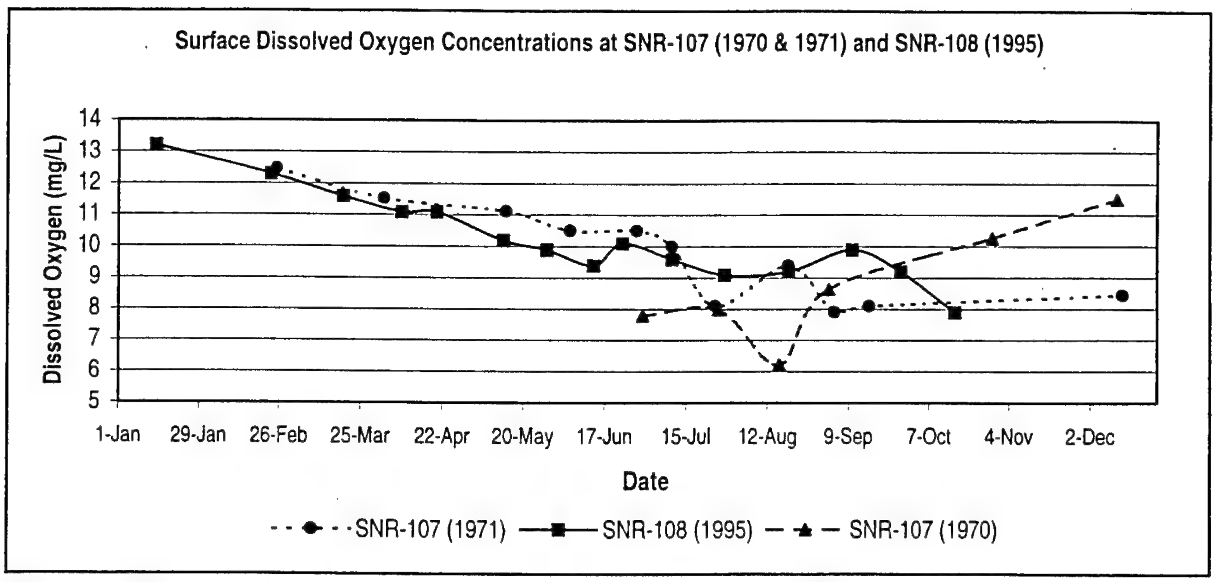


Figure 3-22. Surface Dissolved Oxygen Concentrations at SNR-107 (1970 and 1971) and SNR-108 (1995)

DO concentrations were slightly higher during the spring in 1971 than in 1995, but reached lower concentrations during late-July and late-August when compared to 1995. When compared with the surface temperature data collected in 1970 and 1971 (Figure 3-6), an inverse correlation is apparent.

Peak water temperatures were measured on July 28, August 23, and September 9, 1971, and these sampling occasions were also three of the four lowest DO readings obtained that year.

At the lower Snake River stations, DO concentrations were for the most part above 8.0 mg/L during 1997 except during one late-summer event at each station. The timing of the seasonal low level seemed to occur first upstream (SNR-140) and then progressively moved downstream. The average low concentration for these three Snake River stations during this one sampling event was about 7.0 mg/L. A review of data collected in other years, particularly during the historically low flow conditions in 1994, reveal only minor differences. During an early September sampling event, at Station SNR-108, the average DO concentration dipped to near 6.8 mg/L but remained above 8.0 mg/L for all other sampling events.

The lowest oxygen concentrations recorded during 1997 typically occurred during September. At station SNR-40 (not shown), which is in the tailwater section below the Lower Monumental Dam, the lowest water column concentrations ranged from 6.7 to 6.8 mg/L, or less than 75 percent saturation from the surface to the bottom with an overall depth of 8.0 meters. The next downstream station, SNR-18, which is in the Ice Harbor Reservoir, had DO concentrations ranging from 6.9 to 7.1 mg/L or roughly 76 to 79 percent saturation at depths above 20 meters during the same time interval. Readings at the Clearwater River stations (CLW-1 and CLW-11, not shown) were typically well above 8.0 mg/L and 100 percent saturation, except during mid-September when surface concentrations dropped to 7.5 mg/L or roughly 85 percent saturation at the surface. At the 1.0-meter depth, the DO concentration at the same station decreased to 6.3 mg/L or 71 percent saturation. DO levels at both Clearwater River stations rebounded to 10.0 mg/L or more by late September. Despite these relatively low dissolved oxygen values, it is still important to note that the median percent saturation at both Clearwater River sampling sites was over 100 percent during the 1997 growing season, and the analogous values at SNR-18 and SNR-40 were close to 90 percent.

A few locations had lower concentrations at depth. Station SNR-108, which is at the deepest point in the Lower Granite Reservoir, had low readings of 5.3 and 3.4 mg/L or 59 and 38 percent saturation at depths of 30 and 35 meters, respectively (See Figure 3-23 and 3-24). At depths above 20 meters, DO levels ranged from 7.0 to 7.6 mg/L or 80 to 87 percent saturation. In 1994 and 1995, the lowest readings recorded at SNR-108 at a depth of 34 meters were 2.3 and 4.9 mg/L, respectively. A comparison of DO data collected in 1975 and 1977 at approximately the same time of year suggests that concentrations of DO at depth have decreased over time.

Station SNR-83 in the Little Goose Reservoir just below the confluence of Deadman Creek also had relatively low values of 5.5 and 4.7 mg/L or 62 and 52 percent saturation at depths of 10.0 and 30.0 meters, respectively, during early September 1997. Above 10 meters, DO levels ranged between 5.8 to 7.2 mg/L or 67 to 84 percent saturation. However, prior to this event and by early October, DO levels at all the Snake River stations were near or above 90 percent saturation.

3.2.4.3 Total Dissolved Gas Supersaturation

Nitrogen, oxygen, and argon comprise about 78 percent, 21 percent, and 1 percent, respectively, of the elemental gases in dry air. When the pressure of every gas in the atmosphere reaches

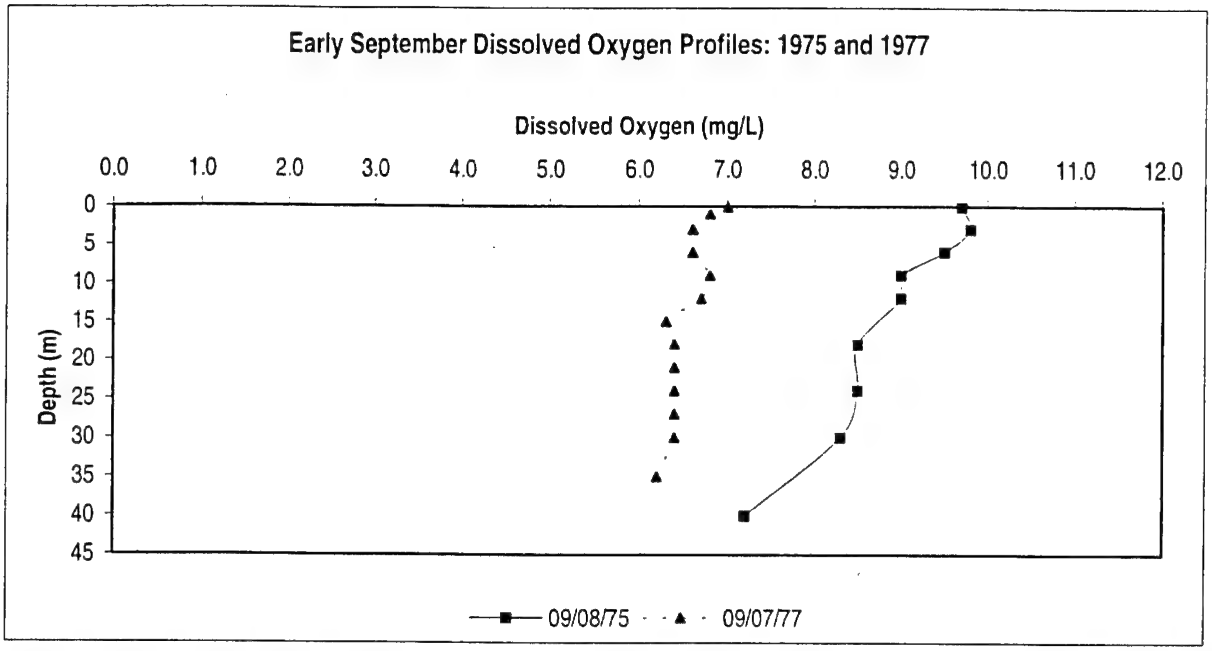


Figure 3-23. Dissolved Oxygen Profiles for Select Days in 1975 and 1977 at Station SNR-108

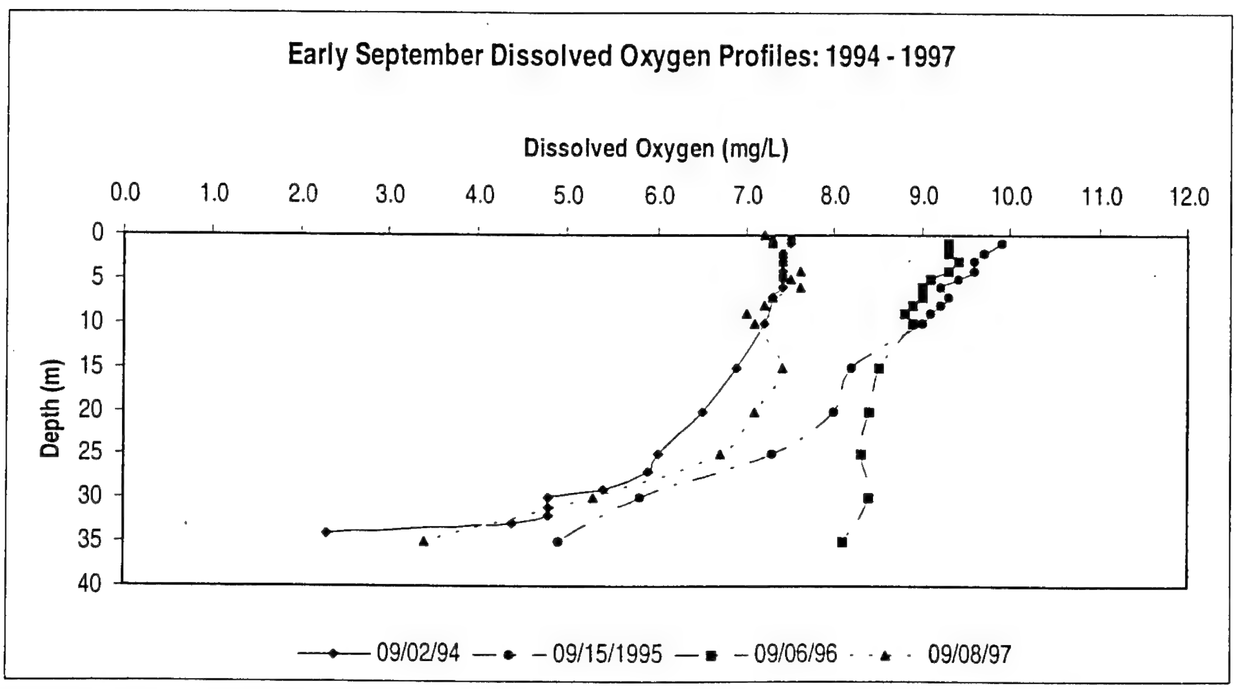


Figure 3-24. Dissolved Oxygen Profiles for Select Days in 1994, 1995, and 1997 at Station SNR-108

equilibrium with its dissolved form in water, the water is said to be saturated. Water is rarely at equilibrium with atmospheric gases but is usually either undersaturated or oversaturated (supersaturated). The pressures of gases in the air make up atmospheric pressure, and its counterpart in water is the TDG pressure. If the TDG pressure is greater than atmospheric pressure, the water is supersaturated.

3.2.4.4 Biological Effects of Total Gas Pressure on Fish and Aquatic Biota

Dissolved gas supersaturation (DGS) is an important issue that has received considerable attention in Canada and the United States (U.S.). DGS can lead to a physiological condition known as gas bubble trauma (GBT) in aquatic biota. GBT can be harmful or even fatal to aquatic organisms, as demonstrated by a number of significant fish kills in the U.S. portion of the Columbia River, and the Snake River (Weitkamp and Katz, 1980; Scholtz et al., 1998).

DGS can produce a variety of physiological signs which are harmful or fatal to fish and other aquatic organisms (Renfro, 1963; Stroud and Nebeker, 1976; Nebeker et al., 1976a, b, and c; Weitkamp and Katz, 1980; Cornacchia and Colt, 1984; Johnson and Katavic, 1984; Gray et al., 1985; Fidler, 1988; White et al., 1991; Fidler and Miller, 1997). As a class, these signs are referred to as GBT or gas bubble disease (GBD). In general, the major signs of GBT that can cause death or high levels of physiological stress in fish include:

- Bubble formation in the cardiovascular system, causing blockage of blood flow, respiratory gas exchange, and death (Stroud and Nebeker, 1976; Weitkamp and Katz, 1980; Fidler, 1988 and 1998a).

- Overinflation and possible rupture of the swim bladder in some species of juvenile (or small) fish, leading to death or problems of overbuoyancy (Shirahata, 1966; Jensen, 1980; Fidler, 1988; Shrimpton et al., 1990a and b).

- Extracorporeal bubble formation in gill lamella of large fish or in the buccal cavity of small fish, leading to blockage of respiratory water flow and death by asphyxiation (Fidler, 1988; Jensen, 1988).

- Sub-dermal emphysema on body surfaces, including the lining of the mouth. Emphysema of the epithelial tissue of the mouth may also contribute to the blockage of respiratory water flow and death by asphyxiation (Fidler, 1988; White et al., 1991).

Other signs of GBT in fish include exopthalmia and ocular lesions (Blahm et al., 1975; Bouck, 1980; Speare, 1990), bubbles in the intestinal tract (Cornacchia and Colt, 1984), loss of swimming ability (Schiewe, 1974), altered blood chemistry (Newcomb, 1976), and reduced growth (Jensen, 1988; Krise et al., 1990), all of which may compromise the survival of fish exposed to DGS over extended periods.

Each sign of GBT involves the growth of gas bubbles internal and/or external to the animal. For each sign of GBT there is a threshold that must be exceeded before bubble formation or swim bladder overinflation will begin (Nebeker et al., 1976c; Fidler, 1988; Shrimpton et al., 1990a). Still, the activation of GBT signs is not an easily demonstrated cause and effect relationship. This is because bubbles that develop internal to the animal may form in several body compartments simultaneously, disrupting neurological, cardiovascular, respiratory, osmoregulatory, and other

physiological functions (Stroud and Nebeker, 1976; Weitkamp and Katz, 1980; Fidler, 1988; Shrimpton et al., 1990a and b; Fidler, 1998a). Thus, depending on the total gas pressure (TGP), the depth of fish in the water column, and the duration of exposure, there may be multiple signs present in affected animals.

GBT may also increase the susceptibility of aquatic organisms to other stressful factors such as bacterial, viral, and fungal infections (Meekin and Turner, 1974; Nebeker et al., 1976b; Weitkamp and Katz, 1980; White et al., 1991). All signs of GBT weaken fish, especially juvenile life stages, thereby increasing their susceptibility to predation (White et al., 1991). Consequently, GBT mortality can result from a variety of both direct and indirect effects caused by DGS.

DGS can affect all aquatic organisms, including fish, invertebrates, and plants. This may lead to alterations in the food chain structure of an aquatic ecosystem. For example, GBT may increase or decrease the availability of a food source for a particular species (White et al., 1991). This may result in the redistributed populations of species either increasing in abundance through colonization or becoming locally extinct (Brammer, 1991). Changes such as this may affect the whole aquatic ecosystem structure.

When describing and analyzing the effects of DGS on fish, it is important to recognize that the signs and consequences of GBT are determined by the exposure history of the fish coupled to the physiological and environmental response of the animal. That is, the effects are expressed in terms of a classic dose - response relationship. In the case of GBT, the dose must include not only the TGP and temperature, but also the depth at which the exposure takes place (Fidler and Miller, 1997; Fidler, 1998a and b). In defining the dose - response relationship, there are four major components that must be considered. Collectively, these components define and set limits for GBT impacts in any aquatic environment. They include:

1) The physical environments in which the exposures take place (i.e., the spatial and temporal distribution of TGP and temperature).
2) The behavior of the animal in that environment (i.e., the spatial and temporal position of the fish in the TGP and temperature fields).
3) The GBT physiological responses of the animal in terms of cardiovascular bubble growth, emphysema of internal and external tissues, swim bladder overinflation, etc.
4) The direct and indirect biological consequence of the physiological response including both acute, and chronic effects.

The first two components define the exposure history or dose, while the third and fourth components define the biological consequences of the exposure. The dependence between the four components can be expressed in the following form:

Physical Environment + Fish Behaviour → Physiological Response → Biological Consequences

All four components are highly dynamic and must be integrated over the entire exposure period in order to define the complete GBT impact. This relationship illustrates that knowledge of the physical environment alone is insufficient to assess the potential for GBT impacts.

Uncertainties as to the effects of DGS on fisheries resources is that biological monitoring programs have failed to demonstrate a correlation between the external and internal signs of GBT observed in feral fish populations and corresponding levels of mortality. Specifically, river physical and biological monitoring, including pit tag analyses, along with related research programs have been unable to quantify the acute, chronic, direct, and indirect effects of DGS on feral fish populations. Also, many aspects of DGS have not been adequately studied, such as its chronic effects on fish, and specifically the effects on invertebrates and aquatic plants. Nor have any attempts been made to examine the effects of DGS on the overall ecology of aquatic communities.

An important distinction to be made in evaluation of TGP trauma effects is associated with the acute versus chronic effects of GBT. The acute effects of GBT usually occur at a Δ P or Δ P' of 76 mmHg and greater, while chronic effects occur at a Δ P or Δ P' of less than 76 mmHg (Fidler and Miller, 1997). However, it is important to note that the distinction between acute and chronic effects cannot necessarily be associated with a particular sign of GBT or TGP.

The dynamics of the exposure environment, coupled to the behavior and physiology of the aquatic organism, will determine the biological impacts, and not the Δ P levels alone. For example, in some situations, intermittent exposures to high Δ P may be relatively unimportant, compared to long term exposures to lower levels of Δ P. It is necessary to acquire a detailed understanding of the cumulative biological effects of DGS on fish and aquatic biota under both steady state and dynamic exposure conditions.

Because of the dynamic nature of the exposure conditions, the physiological responses are also highly dynamic. For example, populations of fish that make frequent changes in depth over the exposure period may require much longer times to develop cardiovascular bubbles and mortality in the population than would be indicated from steady state laboratory bioassay data. Similarly, for fish remaining at constant depth, changes in TGP over the exposure period may result in much longer times to any given level of mortality than would be indicated by steady state laboratory bioassay data.

Only a few studies have examined the acute effects of GBT in resident feral fish populations of rivers (Hildebrand, 1991; White et al., 1991; Lutz, 1995; Scholtz et al., 1998). These have been limited mostly to the observation of external signs of GBT and the incidence of mortality in resident fish captured in shallow water environments. GBT signs and mortality have also been observed in resident fish held near the surface in net pens and monitored when TGP concentrations were above 115-120 percent (Ebel et al., 1975; Toner and Dawely, 1995; Schrank et al., 1997). As the Independent Scientific Advisory Board (ISAB) (1998) points out

> *"natural behavior of resident fish in the wild, such as occupancy of deeper layers, could mitigate the negative effects of supersaturated waters. However many resident fish are obliged to use shallow waters to carry out their life cycles. Early life stages of resident species have been shown to be especially susceptible to GBT above about 110-115 percent. Food organisms such as cladocerans have also shown to develop bubbles in supersaturated water and lose the ability to swim normally. Few invertebrates in the food chain have been monitored adequately, although levels of gas saturation acceptable to fish have been assumed adequate for invertebrates. The monitoring of ecosystem components conducted so far has been inadequate to confidently relate DGS levels believed safe for selected species and ages of migrating salmonids to safety for the mainstem ecosystem as a whole."*

TDG supersaturation has become a major regional concern due to the rapid decline in salmon runs and their listing as an endangered species. High levels of TDG cause mortality in juvenile and adult migratory fish, resident fish, and other organisms. Literature pertaining to the TDG supersaturation problem dates back to the beginning of the century. Dissolved gas control was a major issue in the Pacific Northwest during the late 1970s, and several of the eight Corps dams were retrofitted with spillway deflectors to reduce the level of high TDG supersaturation. These spillway deflectors were designed for involuntary spillway releases, which occur when river discharges exceed powerhouse hydraulic capacities. Recently, operation of the federal projects has changed with the requirement for voluntary spill to assist fish passage. TDG supersaturation has resurfaced as a major regional concern due to increased voluntary spill to improve juvenile fish passage.

Spill at the run-of-river dams on the lower Snake and Columbia rivers causes TDG supersaturation that frequently exceeds 110 percent of barometric pressure. Water passing through the spillways of the dams entrains air bubbles as it passes under the gates, flows over the spillway, and plunges into the stilling basin. Hydrostatic pressure forces the air bubbles into solution, thus raising TDG concentration in the water. As a convenience, dissolved gas pressures may be expressed as a percentage of barometric pressure (percentage of saturation). The TDG supersaturation is often mislabeled as "nitrogen supersaturation," because air is comprised mostly of nitrogen, and nitrogen was believed to be the only gas that caused problems. While nitrogen does speed the problems of gas bubble trauma, all of the dissolved gases in air participate in the process.

Variables that may determine dissolved gas concentrations on run-of-river dams include: (1) the total amount of spill; (2) the amount of spill per spillway bay; (3) the presence and effectiveness of spillway deflectors; (4) dissolved gas concentrations in the forebay; (5) water temperature, and; (6) the depth of the stilling basin relative to the tailwater elevation (i.e., the depth of spill plunge). While relationships between all of these variables have been hypothesized (Roesner and Norton 1971), the significance of several variables is unknown at this point. However, it is known that spill volume and tailwater elevation are very significant factors, and therefore are important in determining operational strategies.

Mathematical relationships, including simple linear regressions and those used in mechanistic computer models (e.g., GASSPILL), use spill discharge to explain most of the variation in TDG concentrations in a specific tailrace. Also important to note is that TDG in the reservoirs can be reduced by wind/wave action, and by shallow tailrace conditions. Other factors determining TDG supersaturation include total river discharge, and downstream mixing of powerhouse and spillway discharges. In addition, water temperature and pressure are both important factors in determining gas solubility. For example, increasing the temperature of water decreases the volume of gas it will hold at equilibrium. Therefore, an increase in water temperature alone will produce supersaturation in water that is initially saturated (Weitkamp and Katz, 1980). Similarly, pressure increases rapidly with depth, as a result of greater hydrostatic pressures. This increase in hydrostatic pressure greatly enhances the capacity of deeper water to dissolve and retain gases in solution.

Dams slow and quiet the water preventing the dissolved gases from equilibrating with the atmospheric air between dams. Consequently, supersaturated conditions can persist and accumulate over extended distances (Corps, 1992b). Ebel (1969) reported that no equilibrium occurred between the four lower Columbia System dams. The problem dwells within the physical properties of various gases and water. At the project spillways, the depth of the plunge pool forces the entrained

air into solution due to the increased surface area and hydrostatic pressure. In addition, with a low diffusion pressure and a low surface-to-volume ratio, the dissolved gas is slow to equilibrate with the atmosphere. An overview of the relationship of gas laws and water can be found in Colt's "Computation of Dissolved Gas Concentrations in Water as Functions of Temperature, Salinity, and Pressure" (1984).

The operation of a powerhouse allows reductions in the amount of spill and minimizes TDG concentrations by diluting the higher dissolved gasses created by spillway operations. However, as spill volumes increase, the dissolved gas levels downstream consistently increase. As the river flow passes each of the lower Snake and Columbia river dams, sequential spill will cause the level of dissolved gas in the river to be incrementally and cumulatively increased. Although the relationship between tailwater TDG levels, forebay TDG levels, and spill discharge is not well defined, forebay TDG levels are known to be transmitted through the powerhouse. Even if forebay TDG is not significantly increased over the spillway, the reduced dilution provided by high-TDG powerhouse flows will result in accumulated TDG levels as the water flows down the system.

3.2.4.5 Existing Measures for Improved Salmonid Survivability

Several measures have been implemented within the project area to improve the downstream migration and survivability of juvenile salmonids. Among these measures are voluntary spillway releases, installation of flow deflectors, other spillway modifications, and transportation system improvements. These measures are discussed below.

Voluntary Spillway Release

To improve conditions for downstream salmon migration and their survivability, the Corps has been releasing water from the eight lower Columbia and lower Snake River facilities as requested by NMFS. These special spillway releases have been ongoing since 1994 and typically occur during the migration season from March through August. The volume of released water consists of up to 100 percent of the total river discharge. The specific requirements for the water releases for fish passage are spelled out in the NMFS 1998 Supplemental Biological Opinion (1998 Biological Opinion). The start and end dates of this voluntary spill were determined by the Technical Management Team (TMT) based on seasonal monitoring information. Planning dates for the spring spill are April 3 to June 20 in the lower Snake River. Within the facility area, a planned summer spill between June 21 and August 31 is only required at the Ice Harbor Dam. Spill periods are for 24 hours a day at Ice Harbor, and from 1800h to 0600h at Lower Monumental, Little Goose, and Lower Granite.

The 1998 Biological Opinion also recommends spring spill at all three Snake River collector facilities (Lower Monumental, Little Goose, and Lower Granite) outside of the time windows mentioned above, "when seasonal average flows are projected to meet or exceed 85 kcfs." In addition, the 1998 Biological Opinion recommends spilling directly up to spill discharge caps that correspond to the 120 percent TDG level below the spilling facilities. The spill discharge caps set to not exceed 120 percent TDG at the tailwater monitoring stations in 1998 were 45 kcfs at Lower Granite, 60 kcfs at Little Goose (though TDG readings led to a 48 kcfs cap), 40 kcfs at Lower Monumental, and 75 kcfs at Ice Harbor (Corps, 1998b). However, the Biological Opinion spill caps for Lower Granite and Little Goose seem to be reversed, as Lower Granite spill cap is 60 kcfs and Little Goose is 45 kcfs. The spill cap at Ice Harbor increased to 100 kcfs in early 1999 resulting

from the addition of spillway flow deflectors on end bays. In-season adjustments to the spill caps are made based on actual TDG readings below the facilities.

Spillway Flow Deflectors

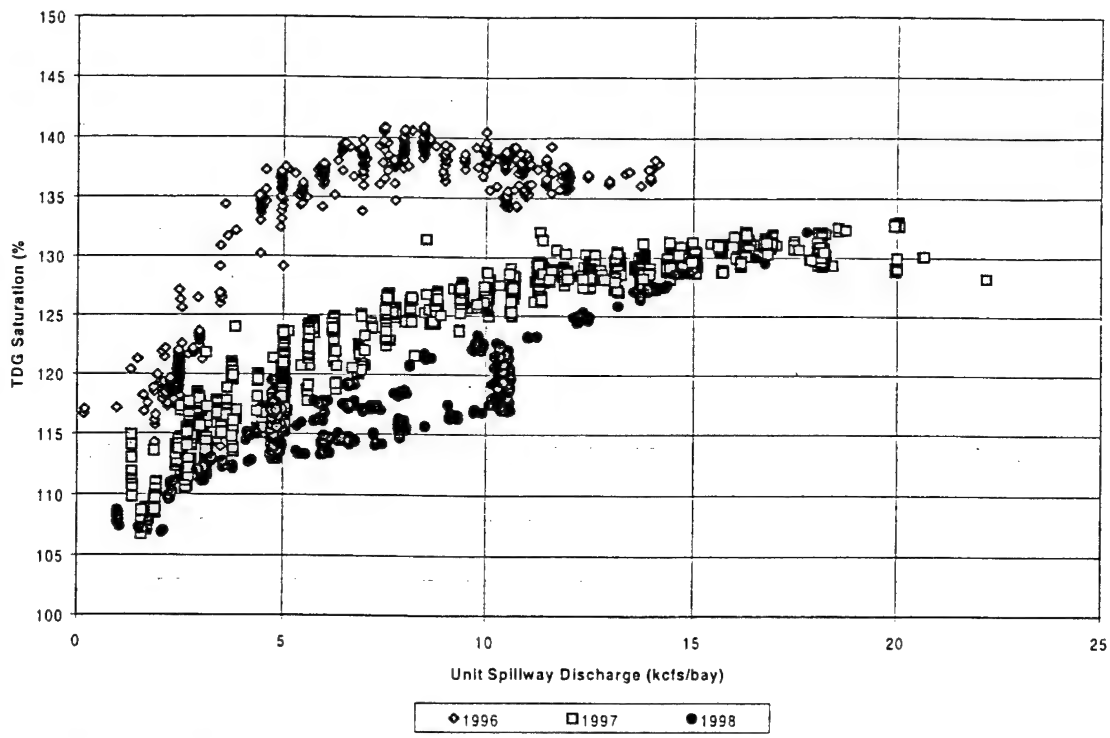
The spillway flow deflectors on the lower Snake River facilities are submerged flip-lips jutting out from the spillway faces, which force spilled water to skim over the surface of the tailwaters instead of plunging deep into the stilling basin. By minimizing the plunging of water into the stilling basin, the generation of TDG supersaturation is also minimized. Originally, spillway deflectors were designed to reduce TDG levels under forced spill conditions when tailwater elevations are high, as in the case of involuntary spills (e.g., when the river flow exceeds the capacity of the powerhouse). The fish passage spill program of the 1990s operates under varying tailwater elevations, including periods when the tailwaters are too low for the spillway deflectors to be effective. Consequently, the spillway discharge overrides the deflectors and plunges deep into the stilling basins, causing TDG levels to increase.

Spillway deflectors were installed in the 1970s at five of the facilities with varying degrees of success in TDG reduction. They were designed for optimal performance under conditions of large involuntary releases associated with high-flow events in the spring. The elevations of the deflectors were determined based on the tailwater elevations associated with those flood events, and therefore their performance under other tailwater conditions is not nearly as effective. Another parameter involved with the design of the deflectors is the amount of flow over the deflector. Generally, the deflectors perform adequately up to a point where the flow is able to override the deflector and establish a plunging flow in the stilling basin. At the time they were designed and installed, the spillway deflectors were viewed as an interim measure that would improve the TDG performance of the spillways until storage capacity and powerhouse capacity could be increased to greatly reduce the need to utilize spillways to pass spring flows. Beginning in the late 1980s, voluntary spillway releases were made for the improvement of juvenile fish passage. As a result, TDG levels increased again because the facility operations are not within the design range of the spillway deflectors.

The effectiveness of a flow deflector will improve if they can be designed to perform over a wider range of spill discharge and tailwater fluctuations. The ideal deflector generates a smooth, stable skimming flow across the water surface of the stilling basin. However the hydraulic performance of existing deflectors is limited to a narrow range of tailwater elevations and unit spill discharges. The deflectors recently constructed at Ice Harbor appear to perform better than other facilities in terms of gas production versus spill discharge. The new deflectors are 3.8 m (12.5 feet) long with a 4.6-meter (15-foot) radius transition (curved surface from the spillway face to the horizontal surface of the deflector) and are set at an elevation that provides optimal performance during the more typical facility operations under the current voluntary spill program. Lower Granite and one deflector out of six at Lower Monumental was also constructed with a 4.6-meter (15-foot) radius. In contrast, the deflectors at Little Goose and McNary Dams do not have a radius fillet. Model studies and prototype evaluations indicate deflectors with a radius transition generate a smoother more stable surface jet. The pier walls between spillway bays at Ice Harbor were also extended to the end of the deflectors. These modifications are relatively low-cost and could provide some benefits by reducing TDG production.

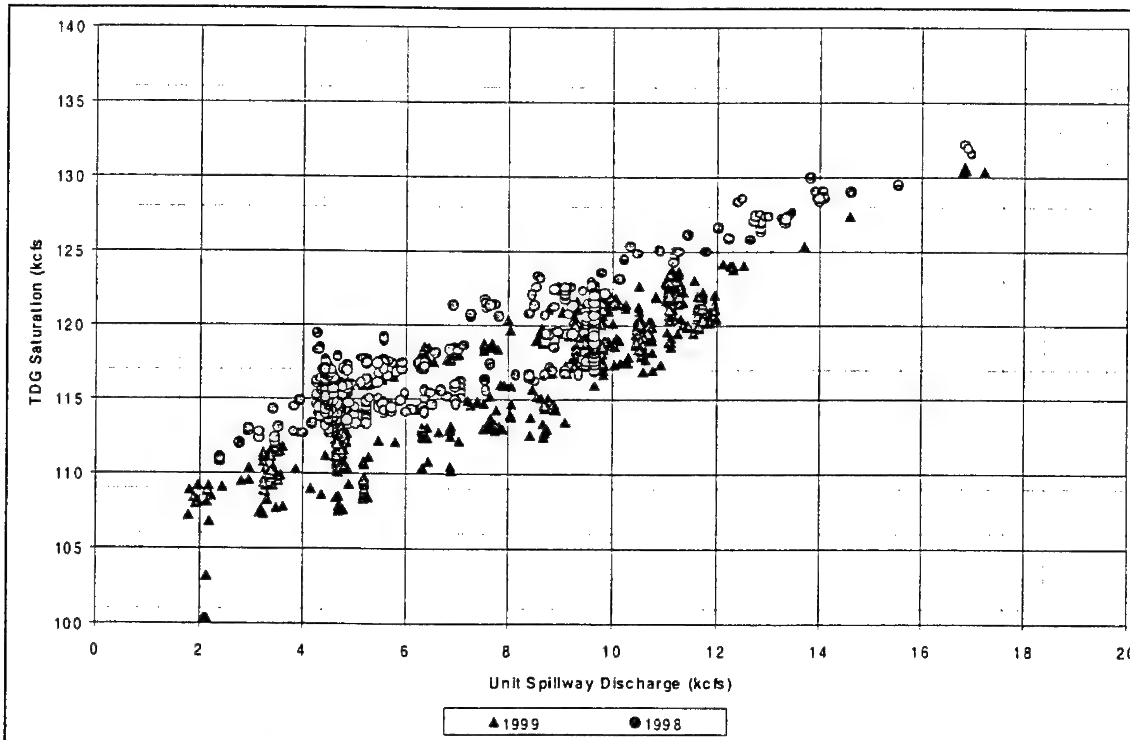
Figure 3-25 shows the percent decrease in TDG Saturation per Unit Spillway Discharge (kcfs/bay) with the addition of flow deflectors at Ice Harbor Dam for 1996 through 1998. Prior to 1996, Ice Harbor Dam was factored out as the most spill limited dam on the lower Snake River and the dam with the highest production of percent-TDG for either voluntary spill-for-fish and involuntary spill. These limits were partially attributable to the lack of structures in the 10 spillways at Ice Harbor to reduce TDG production, such as flow deflectors. The most expedient method to increase the spill volume at Ice Harbor to meet the NMFS request of 120 percent TDG was to design and construct flow deflectors in as many spillbays as deemed necessary without compromising good tailwater hydraulic conditions for adult salmon entrance into the ladders. In the winter of 1996-1997, flow deflectors were scheduled to be installed in 8 of the 10 spillbays, but high flows in January terminated construction, with deflectors installed in only 4 spillways, and leaving 2 additional spillbays inoperable. The configuration of four spillbays with deflectors, two spillbays inoperable, and four spillbays without deflectors in 1997 increased the spill cap for 120 percent TDG to around 45 kcfs from around 25 kcfs without any spillbays with deflectors prior to 1996. The spill cap for the Federal and State water quality standard of 110 percent changed to around 11 kcfs in 1997 from around 5 kcfs prior to 1996 with very little change in spill pattern for adult attraction to the ladders. In 1998, the original construction for deflectors in 8 of the 10 spillbays was completed and resulted in increasing the spill cap for 120 percent TDG to around 75 kcfs by flattening out the TDG production curve. The spill cap for the Federal and state water quality standard of 110 percent changed to around 19 kcfs in 1998 from around 11 kcfs in 1997 with very little change in spill pattern for adult attraction to the ladders. In 1999, construction to complete deflectors in all 10 spillbays resulted in increasing the spill cap for 120 percent TDG to around 90 to 110 kcfs by flattening out the TDG production curve even further (Figure 3-26). The spill cap for the Federal and state water quality standard of 110 percent changed to around 25 to 30 kcfs in 1999 from around 19 kcfs in 1998 with very little change in spill pattern for adult attraction to the ladders. Spill up to 100 percent of the flow when flow was below 110 kcfs during the night was tested beginning in 1999 for percent-TDG and tailwater egress of smolts. The Ice Harbor stilling basin is the only spillway structure on the lower Snake River that has baffle blocks for hydraulic energy dissipation, hence increased potential for incidence of salmonid smolt physical injury and mortality beyond the 2 percent generally assumed for other spillways on the lower Snake River. Spillway passage survival and/or adult passage delay under high spills exceeding 100 kcfs or 100 percent of river flow has not been adequately monitored or tested to date in order to assess the actual acute or cumulative risk to salmonid passage survival.

Spillway elevations are set to provide ideal skimming flow conditions for target spill discharges and associated tailwater elevations. Since the construction of flow deflectors on Snake and Columbia River facilities in the 1970s, system-wide operations of Corps dams have changed. The flow deflectors were designed to reduce peak TDG concentrations generated by high involuntary spill releases when total river flows exceed powerhouse capacity. Current operations of the Corps facilities require a portion of the total river flow to be spilled for juvenile fish passage. The ratio of spill to powerhouse flows is in the Biological Opinion. The Biological Opinion also states that Corps reservoirs are to be operated at minimum operating pool (MOP). MOP, combined with the requirement of spill flows at much lower total river flows, reduces the submergence and compromises the hydraulic performance of the deflector.



Note: No deflectors in 1996, 4 of 10 installed in 1997, 8 of 10 installed in 1998.

Figure 3-25. Total Dissolved Gas Production Below Ice Harbor Dam, 1996-1998



Note: 8 of 10 deflectors installed in 1998, 10 of 10 installed in 1999.

Figure 3-26. Total Dissolved Gas Production Below Ice Harbor Dam, 1998-1999

The TDG reduction performance of deflectors set too high or too low, because of outdated operations, may be improved by raising or lowering it accordingly. Facility-specific operations, for a design range of total river flows, must be established to optimize the deflector elevation. Given the percent-spill requirement and design range of total river flow, the tailwater elevations and unit spill discharges are easily identified. The ideal submergence and deflector elevation can then be determined from physical spillway model studies and prototype evaluations.

The Little Goose and Lower Monumental spillways have deflectors on six of the eight spillway bays, with the potential for the future addition of deflectors on the outer spillway bays (Bays 1 and 8). Though these end-bay deflectors were not installed due to adult fish passage concerns, it is now believed that adding the end-bay deflectors may further reduce TDG levels without adverse impacts to adult passage.

Spillway Deflector Modifications

Modifications to spillway deflectors have been implemented as a means of further reducing TDG concentrations in the lower Snake River. Among the modifications used are pier extensions, which were added to the flow deflectors at the Ice Harbor Dam. These pier extensions extend the downstream face of the existing piers flush to the downstream edge of the flow deflector and prevent the sidewall flow from directly impacting the flow deflector and plunging into the basin. The sidewall flow rises from the corners of the spillway gates and rides 1.8 to 2.4 m (6 to 8 feet) above the surface of the spillway discharge jet. As the sidewall flow reaches the end of the pier walls it expands abruptly. The two jets, one from each side of the wall, converge. The lower portion of the combined jet impacts the exposed section of the deflector immediately below the pier. The upper portion reaches beyond the deflector and plunges into the stilling basin. The extension forces the expansion of sidewall flow to occur further out away from the deflector, where the flow becomes intercepted by the much more dominant deflected surface flow, preventing it from plunging into the basin.

The hydraulic performance of the pier extension has been observed in the spillway sectional models of the Ice Harbor Dam, as well as the prototype structures. Though Ice Harbor deflectors provide excellent gas reduction benefits, it is difficult to determine the overall influence of the pier extension on the TDG performance of those deflectors. However, it is reasonable to expect that by preventing the sidewall flow from entraining air and plunging deep into the stilling basin, the generation of TDGs will be reduced. In addition to reducing the plunging and aeration of flow, the pier walls were recommended to prevent fish, which may be entrained within the lower portion of the sidewall flow, from directly impacting the exposed section of the spillway flow deflector.

3.2.4.6 Dissolved Gas Abatement Study

The Dissolved Gas Abatement Study (DGAS) is a part of the Columbia River Fish Mitigation Program. The goal of the DGAS is, in response to the 1995 NMFS Biological Opinion on Operation of the Federal Columbia River Power System, to identify means to reduce TDG at the eight Corps facilities on the lower Snake and Columbia rivers to the extent economically, technically, and biologically feasible. To date, gas abatement alternatives have been identified and evaluated for potential application at the eight study facilities. Additionally, numerical modeling tools have been developed to help evaluate the complex issues related to gas abatement through more than 300 miles

of river. The next step for DGAS is to evaluate the alternatives and potential implementation scenarios using the numerical modeling tools.

The DGAS includes two parts, a Phase I reconnaissance level report and a Phase II feasibility level report. The Phase I reconnaissance level report was completed in April 1996. The Phase II Report will present and document the results of the DGAS Phase II feasibility-level investigations. The 60 percent draft report presents the status of major components of the DGAS as of December 1998. Most of the background information surrounding dissolved gas issues are discussed in the April 1996 DGAS Phase I Technical Report. This document continues where the Phase I Report ended and will be finalized when the study is complete in the year 2000. To facilitate dissemination of the extensive amount of information developed through this study, this report is being distributed electronically on compact disc. Supporting documentation and technical reports prepared for this phase of DGAS are included on the compact disc in pdf files (portable document format). This format is readable with Adobe Acrobat Reader, which is free software. An Adobe Acrobat Reader installation file is included on the compact disc.

The Phase II gas abatement effort includes a complex system-wide evaluation of alternatives and can be broken into five main tasks: alternative investigations, prototype construction, numerical modeling, biological research, and water quality research. Alternative investigations include the design and localized evaluation of alternatives. Prototype construction includes the construction and testing of an alternative to validate assumptions and estimates developed in the alternative investigations. Numerical modeling includes the development and use of numerical modeling tools to evaluate biological and water quality benefits of gas abatement alternatives throughout the river system. Biological research includes field and laboratory research required to validate assumptions made in the design of alternatives and to calibrate and validate the numerical modeling tools. Water quality research includes field research required to investigate gas production of the existing structures and the alternatives and to investigate transport and mixing characteristics of the river system as needed to develop the numerical modeling tools. Additionally, the program's review by the Independent Scientific Advisory Board is also summarized, as this review played a significant role in changing the scope of this study.

Of the alternatives evaluated in the DGAS, only those that have been "fast-tracked" are included in the Feasibility Study. These include the addition of end bay deflectors at Lower Monumental and Little Goose and the modification of deflectors and pier extensions at Lower Monumental, Little Goose and Lower Granite. These improvements have already been made at Ice Harbor and have proven to be quite successful.

3.2.4.7 Total Suspended Solids

Table 3-3 describes the mean TSS concentrations (mg/L) and 95 percent confidence intervals for a select number of sample sites within the project area, covering a period of up to 24 years. These data indicate that in most cases the average concentrations for each site either increased slightly or were relatively similar. However, it is noteworthy that the 18 mg/L mean determined for SNR-148 in 1997 was due, in large part, to the 65 mg/L value that was observed during early June, when runoff was close to maximum; otherwise, concentrations were less than 10 mg/L most of the time. In the free-flowing reach of the Clearwater River (CLW-1), average concentrations have decreased from 15 mg/L to 4 mg/L between 1976 and 1997. Information for the years between this interval is not present in the current database, but the trend was similar to the one observed in the free-flowing

Table 3-3. Average and 95 Percent Confidence Intervals for Growing Season Total Suspended Solids Concentrations (mg/L) at 1m for Selected Sampling Sites and Years

	1975		1976		1977		1994		1995		1996		1997	
	Avg	CI	Avg	CI	Avg	CI	Avg	CI	Avg	CI	Avg	CI	Avg	CI
SNR-18	ND	ND	ND	ND	ND	ND	ND	ND	10	3 17	11	3 20	9	4 14
SNR-83	ND	ND	8	4 12	14	8 21	ND	ND	6	0 12	10	4 16	20	(2) 41
SNR-108	ND	ND	6	2 10	11	7 15	ND	ND	4	3 6	8	2 13	8	3 14
SNR-118	ND	ND	ND	ND	ND	ND	ND	ND	6	2 9.	ND	ND	10	< 1 20
SNR-129	ND	ND	24	3 46	14	9 19	ND	ND	7	3 11	15	2 29	9	1 16
SNR-148	ND	ND	19	9 30	27	20 34	ND	ND	ND	ND	ND	ND	18	(2) 37
CLW-1	ND	ND	15	4 27	8	3 13	ND	ND	ND	ND	ND	ND	4	0 8

Snake River. Similarly, the 1997 mean value of 20 mg/L at SNR-83 was elevated as a result of the 70 mg/L concentration determined at 1 m on 29 June and due to a near-surface film; the concentration at 12.5 m was only 13 mg/L.

It is generally thought that larger particles transported by the rivers settle out in the transition zone in the vicinity of Lewiston, Idaho, and downstream into Lower Granite Reservoir. Finer material that passes Lower Granite Reservoir remains suspended. As such, the data suggest that there may have been a decrease in the larger fraction of the suspended solids transported by the in-flowing rivers, yet the amount of fines that travel down through the series of dams has remained about the same. Occasionally, elevated concentrations near the surface occur in the reservoirs as a result of localized algal blooms, port operations, and tributaries.

Typically, TSS concentrations are highest during the spring freshet and then decline as flows diminish through late summer and into the fall. Figure 3-27 presents the 1997 observed TSS levels averaged over depth for selected stations within the project area. The highest TSS levels were observed during the early June sampling event and then dramatically decreased with most stations having less than 10 mg/L for the remainder of the season. Based on the measured data, the upstream Columbia River stations (CLR-369 and CLR-397) and the Clearwater River stations (CLW-1 and CLW-11) had the lowest levels in the study area with maximum levels only reaching 164 mg/L and seasonal medians of 2 mg/L. Below the Snake River confluence, in McNary Reservoir, peak levels

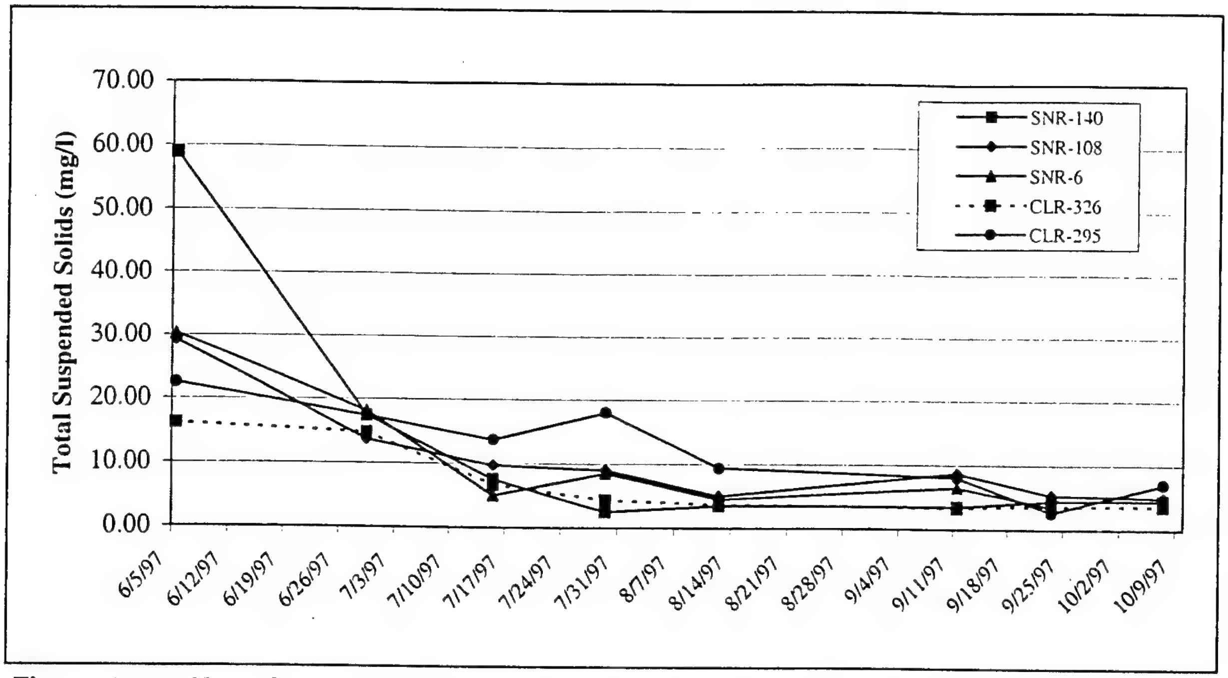


Figure 3-27. Total Suspended Solids for Selected Sampling Stations in 1997

generally ranged from 21 to 32 mg/L at Station CLR-295. At Station CLR-306 (not shown) one particularly high reading of 40 mg/L was measured at a depth of 20 meters in mid-July. During this same event, the corresponding turbidity level was 6 NTUs and the TSS levels at the 1.0 and 10 meter depths were both 6 mg/L. The 1997 data showed that the highest TSS levels were frequently found at the 20-meter depth or greater and these concentrations were often as much 10 mg/L or more than those measured at the 1.0-meter depth.

Within the lower Snake River, the upstream station (Stations SNR-140) had peak TSS levels of 60 and 65 mg/L at the surface and bottom depths, respectively. Station SNR-129, at the uppermost portion of the Lower Granite Reservoir, appeared to have the highest peak level of 72 mg/L at a depth of 20 meters and an average concentration of nearly 50 mg/L throughout the water column. Discharge in the lower Snake River was around 175 kcfs at the time, and the average TSS level throughout the remaining portions of the system was about 30 mg/L with no distinct differences between the impounded and non-impounded reaches. Again, the highest levels were generally observed at the greater sampling depths. By the June 29 sampling date, the average TSS level declined to just below 20 mg/L, except at Station SNR-83 (not shown), which had an unusually high level of 70 mg/L at the surface and much lower levels below. This high TSS level was likely the result of patchy conditions that often occur on the reservoirs. For the remainder of the sampling season, TSS levels were consistently below 20 mg/L and most often below 10 mg/L.

Peak TSS levels in the Palouse and Tucannon Rivers were generally much higher during 1997 than in the mainstem. The Palouse River had a particularly high concentration of 1,035 mg/L in early June as compared to a seasonal low level of 13 mg/L. The Tucannon River recorded the second highest level of 130 mg/L during the spring runoff period (early to mid-June) but levels remained below 10 mg/L after mid-August. The high TSS levels in these two tributaries appeared to have little effect on the observed levels in the lower Snake River. The difference in TSS levels observed

at Stations SNR-40 and SNR-50, which are located downstream of these tributary inputs, were typically less than 5 mg/L and the peak downstream level was no more than 26 mg/L.

There are no state water quality standards for TSS. However, turbidity standards in Idaho and Washington limit increases to 5 nephelometric turbidity units (NTU) when the background is less than 50 NTU except when the flood exceeds the 7-day, 10-year flood frequency (Table 3-1). Turbidity levels of the Snake River exceeded state water quality standards in June 1997 at most stations (Table 3-4).

Table 3-4. 1997 Turbidity Measurements (FTU[1]) in Surface Waters at Selected Snake River Stations

Date	SNR-18	SNR-83	SNR-108	SNR-118	SNR-129	SNR-140
6/2 to 6/9/97	16	17	18	17	17	20
6/28 to 7/1/97	5	9	3	5	5	8
7/3/97	7	NC	NC	NC	NC	NC
7/14 to 7/19/97	4	3	3	2	2	3
7/28 to 7/31/97	4	2	2	3	3	2
8/11 to 8/14/97	5	3	2	2	2	2
9/8 to 9/11/97	3	2	1	2	2	2
9/15/97	3	NC	NC	NC	NC	NC
9/22 to 9/25/97	3	2	2	2	2	2
10/6 to 10/9/97	2	3	3	2	2	2

1/ FTU (formazin turbidity units) are equivalent to NTU (nephelometric turbidity units)

None of the TSS concentrations observed in 1997 would have lethal effects on adult or juvenile salmon (Newcombe and Jensen 1996). Concentrations of 25 mg/L for 4 hours have been shown to reduce feeding rate; higher concentrations up to 1,000 mg/L have shown no deleterious effects on adult salmon other than coughing and apparent stress. One study showed 50 percent mortality of juvenile coho salmon at 509 mg/L TSS (Newcombe and Jensen 1996).

3.2.4.8 Nutrients

Inorganic Nitrogen

Of the various soluble inorganic forms of nitrogen, nitrate plus nitrite (NO_3 + NO_2) was the principal component, often comprising more than 90 percent of the soluble fraction. Nitrate nitrogen concentrations exhibited inter-annual variations at several of the sites, but long-term trends were not apparent. However, two important issues were identified regarding the inorganic nitrogen species. First, nitrate concentrations were consistently greater than ammonia values at almost all stations. Second, the lowest nitrate concentrations were consistently identified in Clearwater River samples,

and higher values were usually determined for the free-flowing Snake River. In 1997, the Clearwater River stations had a median NO_3 concentration of 0.03 mg/L. In comparison, the two upstream lower Snake River stations, SNR-140 and SNR-148, had median NO_3 levels that were much higher, ranging between 0.33 and 0.35 mg/L, while the median NO_3 levels throughout the lower Snake River reach ranged from 0.13 to 0.19 mg/L. These data suggest that the high levels contributed from the middle Snake River reach are slightly diluted by the low levels in the Clearwater River, resulting in moderately high NO_3 levels in the lower Snake River. The two principal tributaries in the lower Snake River reach, the Palouse and Tucannon Rivers, had relatively high median levels of 1.38 and 0.21 mg/L, respectively. The Columbia River stations generally had lower NO_3 levels than those observed in the Snake River with median levels ranging between 0.07 and 0.13 mg/L.

Total nitrogen (total-N) levels, which include both the inorganic and organic components, were relatively high in the Snake River stations. Figure 3-28 illustrates the temporal and spatial variability in total-N levels throughout the project area during the 1997 season. Total-N levels at the upstream Snake River station (SNR-140) were generally higher than those observed at the other sampling stations. In general, concentrations decreased throughout the lower Snake River, but were still higher than those observed in the Columbia River. In the spring and summer, the total-N levels increased from about 0.30 to 0.60 mg/L at the lower Snake River stations compared to concentrations ranging from 0.20 to 0.40 mg/L at the Columbia River stations. The total-N levels increased considerably in the fall with peak levels at the Snake River stations reaching 0.8 to 1.1 mg/L in October. This late-season increase may be due to a reduction in plant uptake associated with aquatic plant and algae dying back or going dormant as well as agricultural harvesting in the watershed. Early fall rains after prolonged dry periods also increase nutrient concentrations. A corresponding increase in TSS levels was not detected. The seasonal pattern of nitrogen concentrations is also apparent in nitrate data collected in 1971 at SNR-107, prior to construction of the Lower Granite Dam and SNR-108 in 1995 (Figure 3-29). Nitrate levels were generally highest in spring and fall, likely due to the lower biological uptake during the non-growing season. Concentrations of nitrate were generally similar during the growing season for the 1971 and 1995 data.

This late-season increase in the Snake River levels most likely caused the levels at Station CLR-295, in the McNary Reservoir, to nearly double from around 0.20 to 0.40 mg/L, while the upstream Columbia River station remained constant at just under 0.20 mg/L through the fall period.

The Palouse River, again, generally had the highest levels in the study area with an overall median level of 2.15 mg/L. During the spring runoff, peak levels in the Palouse River reached as high as 4.86 mg/L compared to a peak level of 1.00 mg/L at SNR-140. The influence of these high levels from the Palouse River, however, seem to be localized since there was only a slight increase in the peak levels observed downstream at SNR-40 (1.35 mg/L) as compared to 1.05 mg/L at SNR-50. For most of the sampling period, observed levels between these two stations were essentially the same.

Phosphorus

Phosphorus is generally expressed in terms of total phosphorus and ortho-phosphorus. Ortho-phosphorus (ortho-P) represents the inorganic soluble fraction of the total phosphorus in water and is

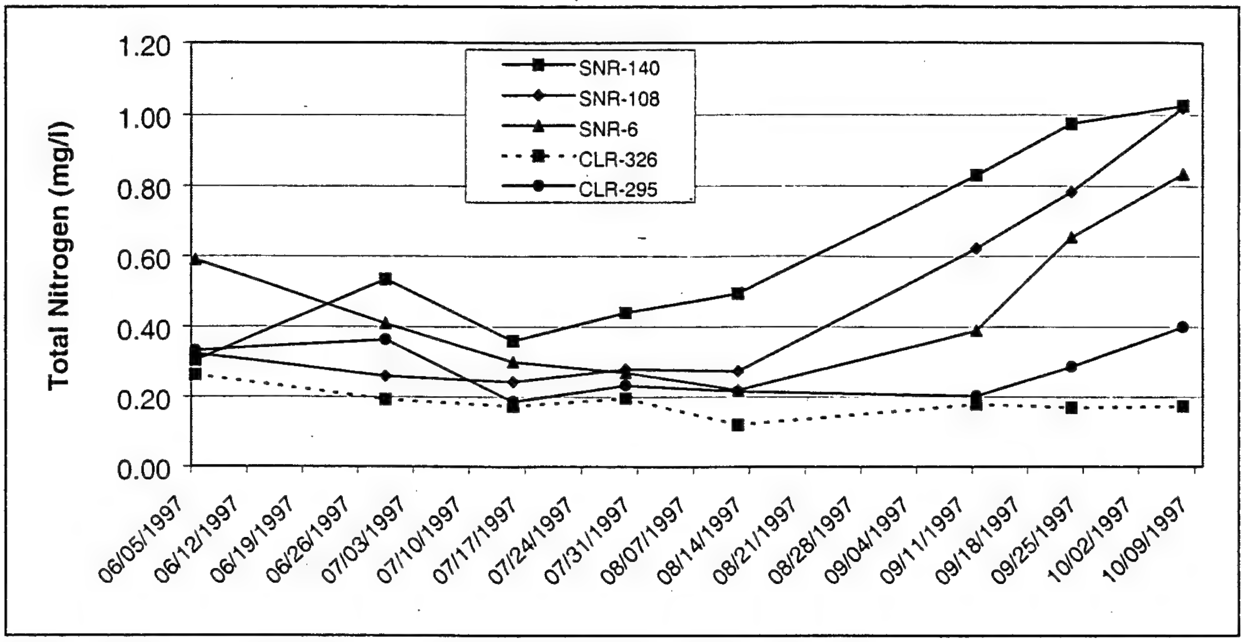


Figure 3-28. Total Nitrogen for Selected Sampling Stations in 1997

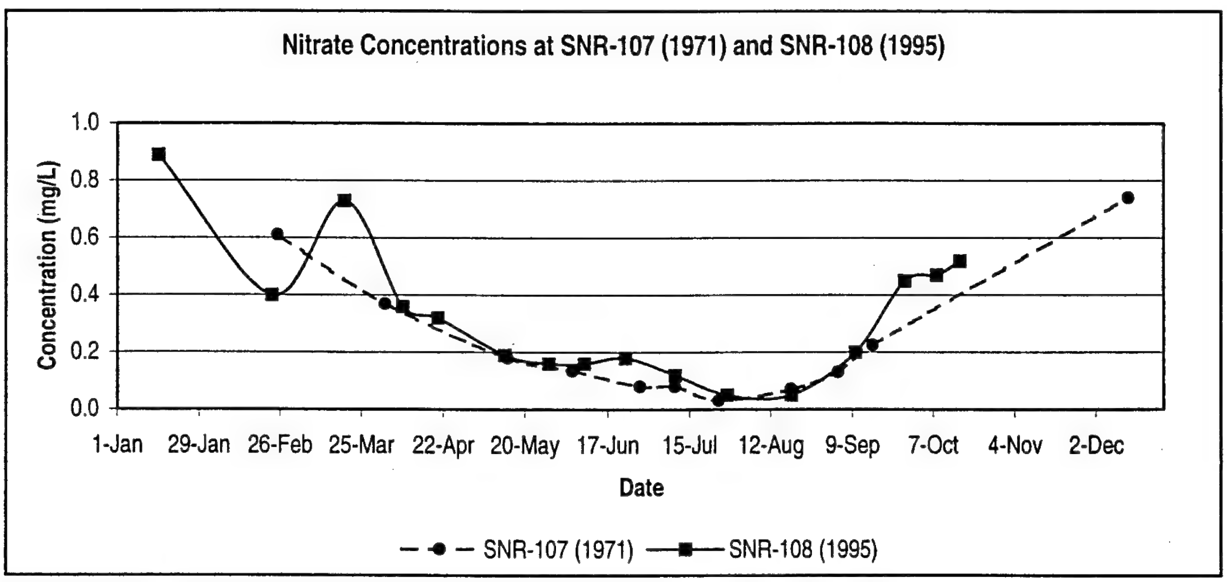


Figure 3-29. Nitrate for Selected Sampling Stations in 1971 and 1995

generally considered to be more readily available for biological uptake than is total phosphorus. Total phosphorus consists of both the soluble fraction and that portion adsorbed to sediments or tied up with biological materials in the water column. Since phosphorus readily attaches to and travels with sediments, adsorbed or biological quantities usually represent the largest portion of total phosphorus. In low-oxygen conditions, the adsorption bond between phosphorus and the sediment particle becomes unstable and often results in a release of the adsorbed phosphorus into the water column. In contrast to nitrogen, phosphorus is usually the limiting nutrient for plant growth in freshwater systems (Wetzel, 1983). However, N:P ratios in the lower Snake, which range from 9-11 (Normandeau, 1999a), are inconclusive with respect to the rate limiting nutrient. Therefore, it is unclear whether substantial increases in phosphorus levels would lead to increased algal productivity and macrophyte growth.

Recent and historical data suggest that ortho-P levels in the lower Snake River tend to be highest in the spring and fall, with relatively low concentrations in the summer (Figure 3-30). The lower levels during the summer are most likely due to biological uptake by aquatic plant and algal growth. As plant growth diminishes in the fall, the phosphorus levels increase, which was most evident at the reservoir stations where algal growth is usually most abundant. In the Columbia River and the free-flowing river stations, there was little change in the ortho-P levels during the sampling season.

The Clearwater River had relatively low ortho-P levels ranging from 0.006 mg/L in the spring to a low of 0.001 mg/L in the mid-summer and up to 0.003 mg/L in the fall. At RM 140, upstream of the confluence with the Clearwater River, ortho-P levels generally ranged from 0.013 to 0.023 mg/L through the summer and from 0.054 and 0.059 mg/L in the fall. Throughout the lower Snake reach, ortho-P levels through mid-August peaked at 0.018 mg/L and increased to 0.022 to 0.063 mg/L from mid-September through October. In the Columbia River, ortho-P levels were comparatively low with most levels below 0.008 mg/L and a peak level of only 0.016 mg/L in the McNary Reservoir during the fall. This comparison of data clearly indicates that ortho-P is much more available throughout the lower Snake River reach relative to other major rivers in the area.

Total phosphorus (TP) levels were also relatively low in both the Clearwater and Columbia Rivers. Median TP levels for both rivers were between 0.010 and 0.013 mg/L. Peak levels, which typically occurred during the spring freshet, were as high as 0.018 and 0.028 mg/L for the Clearwater and the Columbia Rivers, respectively. Again, the highest levels in the study area were measured in the upper portions of the lower Snake reach. During the spring freshet, TP levels (water column average) throughout the lower Snake River ranged from around 0.060 to 0.11 mg/L (Figure 3-31).

The high TP levels during this time of year are most likely attributable to the suspended sediment contained in the peak flow period. For much of the 1997 growing season, TP levels generally ranged from 0.035 to 0.060 mg/L and then steadily increased in the fall. Similar concentrations were observed in 1994 and 1995, where concentrations ranged from 0.025 to 0.060 mg/L in the summer and then increased to around 0.09 mg/L in the fall.

In the Columbia River, the upstream station had a much lower peak TP level of 0.03 mg/L as compared to the downstream lower McNary Reservoir (CLR-295), which had a peak TP level close to 0.06 mg/L. TP levels were lowest during the July and August period throughout the study area, with levels ranging between 0.02 and 0.04 mg/L. In September, the TP levels steadily increased, with levels at the three lower Snake River stations ranging between 0.05 and 0.10 mg/L.

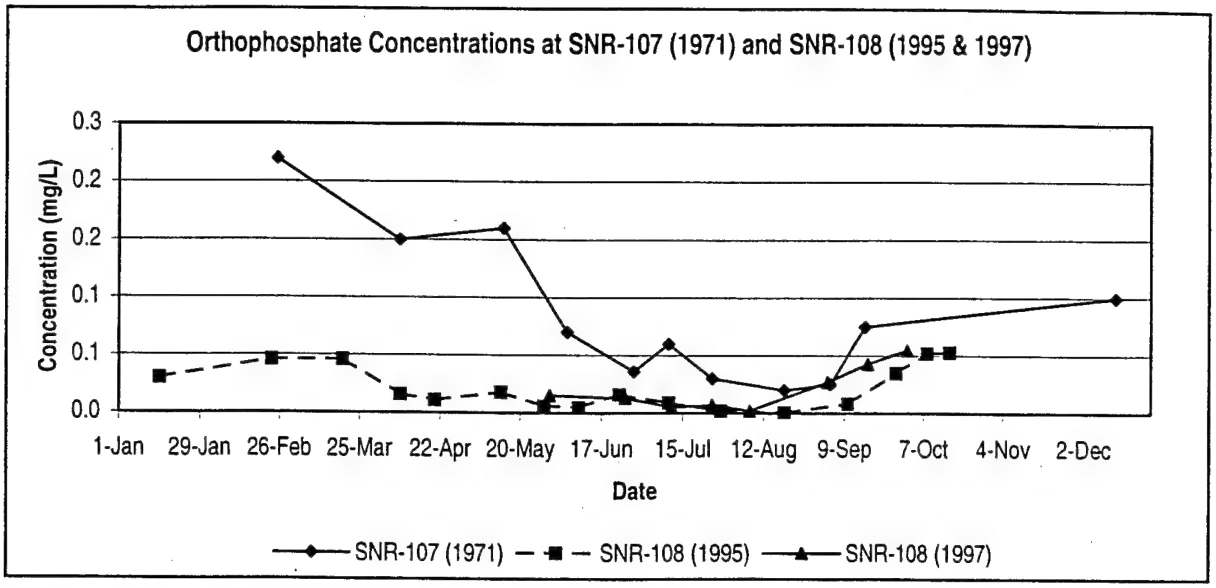


Figure 3-30. Orthophosphate Concentrations at SNR-107 prior to Construction of the Lower Granite Dam (1971), and After Dam Construction (1995 & 1997)

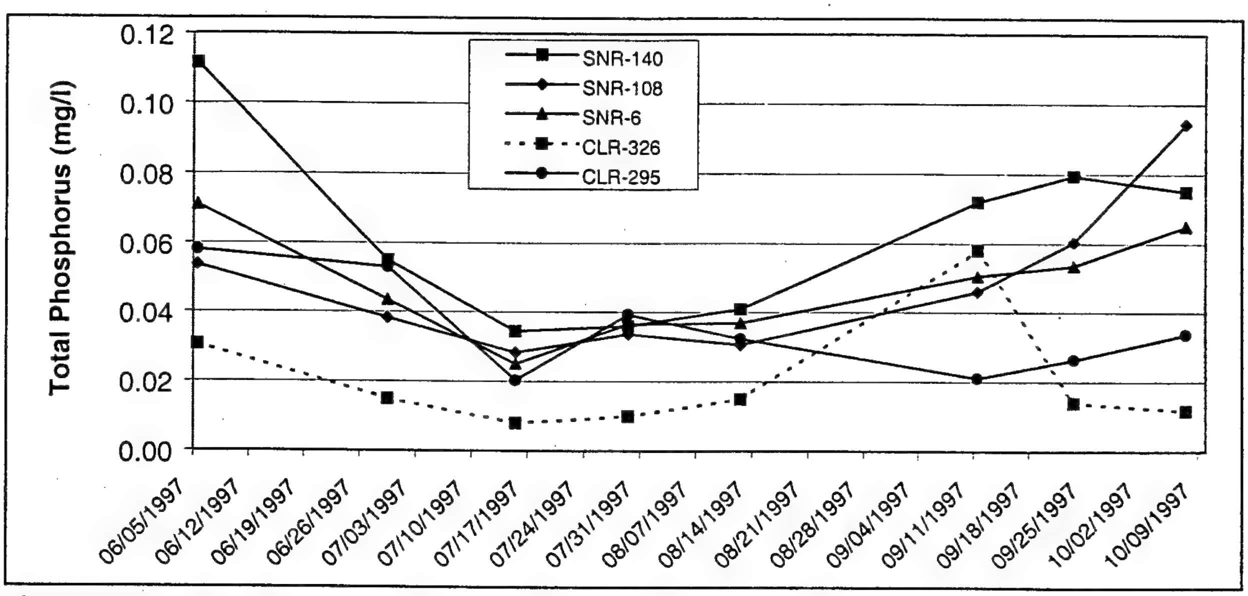


Figure 3-31. Phosphorus for Selected Sampling Stations in 1997

According to the Washington state water quality standards, total phosphorus levels above 0.020 and 0.035 mg/L are considered to be critical thresholds in terms of preventing excessive algal growth when ambient trophic conditions are considered to be in the lower and upper mesotrophic categories, respectively. Oligotrophic conditions represent high quality waters with good water clarity and low algal production and eutrophic conditions represent high nutrient levels, excessive algal growth and poor water clarity. Mesotrophic conditions are somewhere in the middle and typically represent moderate levels of algal production, water clarity and light transparency.

Limnological conditions in the lower Snake River impoundments have generally been considered to be in the upper mesotrophic to eutrophic category (Normandeau, 1999a). Based on a review of the 1997 data, the average phosphorus levels throughout lower Snake River appear to be in the 0.030 to 0.040 mg/L range during the mid-summer and slightly higher to near the 0.060 to 0.070 mg/L range during June and fall months. This would suggest that the average phosphorus levels in the lower Snake River for much of the entire growing season would likely be above the WDOE phosphorus guideline of 0.035 mg/L that was established to maintain existing conditions and prevent eutrophic conditions.

Both the Palouse and Tucannon Rivers had much higher levels throughout the 1997 sampling period. Observed TP levels ranged from 0.062 to 0.212 mg/L and 0.100 to 0.287 mg/L in the Palouse and Tucannon Rivers, respectively. However, due to the substantial difference in flow levels, these high TP levels did not appear to dramatically change measured levels in the main stem of the Snake River.

3.3 Sediment Quality

The results of the recent field investigations performed by the Corps are supplemented by data collected by others within the Columbia River drainage basin. These include the Bi-State Study of the Lower Columbia River and the 1990 and 1997 Corps Surveys, which are all referenced as supporting sources of information for the development of the Dredged Material Evaluation Framework for the Lower Columbia River Management Area (Corps, 1998c).

During the Phase 2 sampling program 94 sediment samples were collected from the lower Snake River and submitted for the laboratory analysis of selected inorganic and organic constituents (Section 2.5). The results of the laboratory analysis for the composite or top layer samples are summarized in subsequent sections of this report, with detailed information regarding the number of samples above detection limits, minimum and maximum values, arithmetic and geometric means, and standard deviations presented in Normandeau 1999b.

3.3.1 Sediment Particle Size

As described in Section 2.5, a total of 487 grab sediment samples were collected as part of the Phase 1 task. Of the 487 grab samples, 356 were sieved to develop particle-size distributions. The remaining 131 samples (or 26.9 percent) were not sieved either because there was no sample recovery or because the sample consisted only of gravel and/or cobble. The average grain size distributions for the sediment samples collected from above the Ice Harbor, Lower Monumental, Little Goose, and Lower Granite Dams are summarized in Table 3-5.

The mean grain size for the channel bed sediments ranges from very fine sand to silt/clay. The highest concentration of relatively coarser sediments (fine to medium sand) was found in Lake

Table 3-5. Summary of Sieve Test Results for Sediment Samples Collected from the Lower Snake River in 1997

	Average Grain Size (in percent)				Cumulative percent			
Sediment Size	**IHR**	**LM**	**LGO**	**LGR**	**IHR**	**LM**	**LGO**	**LGR**
Gravel	2.4	2.8	1.9	0.4	2.4	2.8	1.9	0.4
Very Fine Gravel	0.1	0.6	0.7	0.3	2.5	3.4	2.6	0.7
Very Coarse Sand	0.1	1	0.7	0.5	2.6	4.4	3.3	1.2
Coarse Sand	1.1	1.1	2.8	1.7	3.7	5.5	6.1	2.9
Medium Sand	18.3	2.8	10.2	6.9	22	8.3	16.3	9.8
Fine Sand	18.3	6.7	13.1	17.1	40.3	15	29.4	26.9
Very Fine Sand	23.3	13.2	16.8	20.1	63.6	28.2	46.2	47
Silt/Clay	35.8	71.8	53.8	52.4	99.4	100	100	99.4

Note:
IHR - Ice Harbor Reservoir (Lake Sacajawea), 41 samples
LM - Lower Monumental Reservoir (Lake West), 77 samples
LGO - Little Goose Reservoir (Lake Bryan), 127 samples
LGR - Lower Granite Reservoir (Lower Granite Lake), 104 samples

Sacajawea, above the Ice Harbor Dam. The highest concentration of silt/clay size sediments was found in Lake West, above the Lower Monumental Dam. Fine-grain sediments are concentrated on the channel bottom in Lake West. The concentration of these fine grain sediments is most likely associated with the discharge of the Palouse River into Lake West. This contribution is evidenced by the elevated TSS concentrations in the water quality samples collected from the Palouse River (refer to TSS section of this report). Soil erosion within the Palouse River drainage basin has been documented as a chronic problem due to historical land use practices (Ebbert and Roe, 1998). Recent studies have also documented that the adoption of erosion control practices within the drainage basin has resulted in an observable decline in suspended sediment concentrations in the Palouse River (Ebbert and Roe, 1998), and as a result, probably also into Lake West.

3.3.2 Organics

The sediment samples were tested for the following organic compound groups: chlorinated herbicides, dioxins, glyphosate herbicide, organochlorine pesticides, organophosphorus pesticides, semi-volatile compounds, and total petroleum hydrocarbons. No chlorinated herbicides, organophosphorus pesticides or semi-volatile organic compounds were detected at any of the composite or top layer sediment samples. The following sections discuss the results of the dioxin, glyphosate herbicide, organochlorine pesticides, and total petroleum hydrocarbon analyses.

3.3.2.1 Dioxins

Four sediment samples collected from the Lower Granite Lake were analyzed for dioxins (tetrachloro-dibenzo-p-dioxin or TCDD). The reason for only collecting samples from this portion of the study area was that it is located immediately downstream of the Clarkston-Lewiston area, where industrial discharges may have released this organic compound.

Total dioxins were detected in two of the four samples analyzed, with their concentration ranging from 0.69 to 1.00 ppt (parts per trillion) at an analytical detection limit of 0.4 ppt. The two samples having detectable concentrations of total dioxins were collected from sampling stations LGR 8-3 (0.69 ppt) and LGR 13-7 (1.00 ppt), which are located in the upper portion of Lower Granite Lake. These concentrations are within the lower range of concentrations identified in studies of the lower Columbia River and the lower Willamette River (Bi-State Study and 1990 Portland Army Corps of Engineers Survey) (Corps, 1998c).

In Lower Granite Lake the total dioxin concentrations decrease from upstream to downstream, with no detectable concentrations of total dioxins identified in the samples collected from stations LGR 5-8 and LGR 6-4. The trend of decreasing total dioxins concentrations with increasing distance downstream would suggest that the source(s) for these organic compounds is located upstream of the study area. No specific screening level for dioxin has been established for sediments in the Columbia River.

3.3.2.2 Glyphosate and AMPA

Glyphosate (N-(phosphonomethyl)glycine) is a postemergence herbicide that has found widespread agricultural and domestic use. It is sold as a terrestrial and aquatic herbicide. A major metabolite of Glyphosate is aminomethylphosphonic acid (AMPA).

All top layer sediment samples (94 total samples) were tested for glyphosate and AMPA. Glyphosate was detected in 36 percent of the samples and AMPA was detected in 16 percent of the samples tested. The concentration of glyphosate ranged from non-detected to a maximum of 68.9 ppb (parts per billion) with an arithmetic mean of 12.52 ppb. The concentration of AMPA ranged from non-detected to a maximum of 29.3 ppb with and arithmetic mean of 7.48 ppb (Normandeau, 1999b). No screening criteria have been established for either glyphosate or AMPA in sediments within the Columbia River Basin.

Glyphosate and AMPA were detected in sediment samples collected from each of the impoundments. The highest individual concentrations of glyphosate and AMPA were detected in samples collected from Lake Bryan (upstream of the Little Goose Dam) (Normandeau 1999b). The highest average reach concentration of glyphosate was found in the samples collected from Lake Sacajawea (upstream of the Ice Harbor Dam, see Table 3-6).

Table 3-6. Summary of Average Glyphosate and AMPA Concentrations (μg/L, Elutriate, and ppb, Sediment) for Sediment Samples Collected during 1997 in the Lower Snake River

	Ice Harbor	Little Goose	Lower Granite	Lower Monumental	Average
Elutriate					
AMPA	ND	ND	ND	ND	ND
Glyphosate	0.58	0.69	ND	ND	0.57
Sediment					
AMPA	8.08	7.58	6.07	8.28	7.48
Glyphosate	16.80	10.42	10.60	14.85	12.52

1/ ND = Not detected; ½ the detection level is used when concentrations < detection level.

The highest average reach concentration of AMPA was found in the samples collected from Lake West (upstream of Lower Monumental Dam).

The suspected source of glyphosate and AMPA in the lower Snake River sediments is runoff from surrounding uplands and through transport via stream flow. Sources for these organic compounds may include agricultural, industrial, municipal or domestic uses within the watershed.

3.3.2.3 Organochlorine Pesticides

Several organochlorine pesticides were detected in the sediment samples collected from the lower Snake River. The organochlorine pesticide compounds detected (and their frequency of detection) included: 4,4-DDD (11), 4,4-DDE (43), 4,4-DDT (5), aldrin (3), dieldrin (4), endrin (1), heptachlor (1) and lindane (3) (Normandeau 1999b, see Table 3-7). The three principal organochlorine pesticide compounds detected in the sediments are related, with DDT being the parent compound and DDD-DDE being daughter products generated by the transformation of DDT in the environment (Callahan et al., 1979).

Table 3-7. Summary of Average Concentrations (ppb) of Organochlorine Pesticides and TPH in Sediments Collected during 1997 in the Lower Snake River

	Ice Harbor	Little Goose	Lower Granite	Lower Monumental	Average
Sediment					
4,4-DDD	ND	1.95	3.06	1.58	2.07
4,4-DDE	2.68	4.91	6.48	4.22	4.89
4,4-DDT	ND	1.64	1.72	1.56	1.62
Aldrin	0.75	0.84	0.87	0.82	0.83
Dieldrin	ND	1.74	ND	1.80	1.68
Endrin	ND	ND	ND	1.75	1.58
Lindane	ND	0.91	ND	0.90	0.85
TPH	67.63	45.86	58.25	49.15	55.41

ND = Not detected; average uses ½ of detection when concentrations < detection level.

The predominant organochlorine compound detected was DDE, which ranged in average concentration from 2.68 in Ice Harbor to 6.48 in Lower Granite Reach, with an arithmetic mean concentration of 4.89 ppb. DDD was detected in 11 sediment samples with an average maximum concentration of 6.48 ppb in Lower Granite Reach and an arithmetic mean of 2.07 ppb. DDT was detected in only five samples with a mean arithmetic concentration of 1.62 ppb.

Total DDT (DDD, DDE and DDT) concentrations ranged from non-detect to 32.8 ppb with an average concentration of 8.23 ppb (Normandeau 1999b, Table 3-6). The highest mean reach concentration for total DDT was 11.3 ppb for Lower Granite Lake. The average reach concentration of total DDT decreases steadily from Lower Granite Lake down to 5.7 ppb as recorded in Lake Sacajawea. The maximum and average total DDT concentrations in the lower Snake River sediments exceed the guidance levels set forth in "Puget Sound Dredged Disposal Analysis Guidance Manual: Data Quality Evaluation for Proposed Dredged Material Disposal Projects" PTI,

1989a or recommended screening concentration (6.9 ppb), but are lower than the bioaccumulation trigger concentration of 50 ppb as established in the Dredged Material Evaluation Framework (DMEF) (Corps 1998c). Concentration levels above the screening level prompt biological testing to ascertain health risks to aquatic organisms using the DMEF (Corps 1998c).

The pesticides aldrin, dieldrin, endrin, heptachlor and lindane were all detected in five or less of the 94 sediment samples. The concentration of aldrin ranged from non-detect to 3.5 ppb, dieldrin from non-detect to 8.0 ppb, endrin from non-detect to 9.4 ppb, heptachlor from non-detect to 4.9 ppb and lindane from non-detect to 5.5 ppb (Normandeau, 1999b). The maximum concentrations of aldrin, dieldrin, heptachlor, and lindane in the Snake River sediment are lower than their screening level concentration of 10 ppb. No screening level has been established for endrin in the DMEF (Corps 1998c).

A recent report by the USGS (Clark and Maret, 1998) documents the results of the collection and analysis of bed sediments from the Snake River upstream of the study area. The only organochlorine compound detected in all of the bed sediment samples analyzed by the USGS was DDE at concentrations ranging from 1 to 11 ppb. These concentrations are similar to those reported for the sediment samples analyzed for this investigation. Reports of previous investigations performed on the lower Columbia River (Bi-State Study and Portland Corps 1997 Survey) also document that pesticides are typically only detected at low concentrations (Corps, 1998c).

3.3.2.4 Total Petroleum Hydrocarbons (TPH)

A modified version of EPA Method 418.1 was used for the analysis of the sediments to determine the concentration of petroleum products. Use of this analytical method only provides an indication of the amount of petroleum material in the sediments but does not quantitatively identify the specific type of petroleum material present.

The concentration of TPH ranged from non-detect to 256 ppm (LM 1-2) with an arithmetic mean of 55.41 ppm (Normandeau, 1999b). Along the lower Snake River, the average concentration of TPH generally increases in the downstream direction with the highest average reach concentration (62.13 ppm) found in Lake Sacajawea. No screening level has been established for TPH under the DMEF (Corps 1998c).

3.3.3 Metals

Each of the 94 sediment samples were analyzed for a suite of 18 metals (inorganics). The metals analyzed included: arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, thallium, vanadium and zinc. Of the 18 metals analyzed only cadmium, mercury, silver and strontium were not detected in all 94 samples. Cadmium was detected in only two samples, mercury in 37 samples, silver was not detected in any of the samples, and strontium was detected in only 4 samples (Normandeau, 1999b).

The metal consistently found in the highest concentrations was manganese. This metal is commonly detected in river sediments due to its high relative abundance in the natural environment.

Concentrations of manganese in individual sediment samples collected from the lower Snake River during this investigation ranged from 250 ppm to 1,044 ppm with an average concentration of 430 ppm (Normandeau, 1999b). In comparison, the concentration of manganese in sediment samples

collected upstream of the study area by the USGS (Clark and Maret, 1998), ranged from 370 ppm to 1,000 ppm with an average concentration of 564 ppm.

No consistent trends in sediment metal concentrations were observed going downstream from Lower Granite Lake to Lake Sacajawea (Table 3-8). When compared with the results obtained by the USGS (Clark and Maret, 1998) in their investigation of the Snake River upstream of the study area several trends do become apparent. In the USGS investigation bed sediments were collected and analyzed for a broad range of trace elements. Upstream concentrations of arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc (USGS) were lower than downstream concentrations (this investigation).

Table 3-8. Summary of Mean Metal Concentrations for Sediment Samples Collected during Phase 2 (1997) in the Lower Snake River

Metal (mg/kg)	Ice Harbor	Lower Monumental	Little Goose	Lower Granite
Arsenic	6.3	3.9	6	5.2
Barium	170.6	157.2	192.7	180.8
Beryllium	0.6	0.6	0.7	0.7
Cadmium	ND	ND	ND	0.1
Chromium	20.2	17.7	22.4	23
Cobalt	10.9	8.2	11.1	12
Copper	20.8	16.8	24.8	29.8
Lead	10.5	8.8	12.6	12.9
Manganese	510.1	384.6	475.2	408.9
Mercury	0.1	0.1	0.1	0.1
Molybdenum	0.3	0.2	0.2	0.3
Nickel	14.2	12.4	15.6	16.6
Selenium	1.6	1.4	1.3	1.5
Silver	ND	ND	ND	ND
Strontium	0.1	0.1	ND	0.1
Thallium	0.2	0.2	0.2	0.2
Vanadium	45.1	37.9	47.2	60.9
Zinc	52.5	45	57.3	61.4

Note: all concentrations in mg/kg (ppm)
Ice Harbor Dam - Lake Sacajawea
Lower Monumental Dam - Lake West
Little Goose Dam - Lake Bryan
Lower Granite Dam – Lower Granite Lake

Concentration values for metals in sediments are also available for the lower Columbia River drainage basin (Bi-State Study and 1997 Corps Survey). Of the reported values for the metals arsenic, cadmium, copper, lead, mercury, nickel, silver, and zinc in these previous investigations, only the concentration of arsenic and lead were found to be slightly higher for the samples collected from the lower Snake River during this investigation.

In the Draft Dredged Material Evaluation Framework (Corps, 1998c), the high frequency of detection of metals in the sediments of the lower Columbia River can be attributed to the fact that all of the metals are naturally occurring. Because none of the metals has been found to exceed proposed screening levels, there is no evidence that they are highly concentrated, indicating that there is limited alteration of sediment quality by anthropogenic sources (Corps, 1998c).

3.3.4 Nutrients

A total of 84 of the sediment samples were also analyzed for a number of chemical parameters, designated as the nutrient group (although not all of the parameters are true nutrients). The sediments were analyzed for: ammonia, total Kjeldahl nitrogen (TKN), nitrogen as nitrate/nitrite, total organic nitrogen, total organic matter, pH, phosphorus bicarbonate and sulfate. The mean reach concentrations for each of the nutrient group parameters are summarized in Table 3-9. No screening levels have been established under the DMEF (Corps, 1998c) for nutrients, and comparison with water quality standards is not appropriate.

Table 3-9. Summary of Mean Nutrient Concentrations for Sediment Samples Collected during Phase 2 (1997) in the Lower Snake River

Parameter	Ice Harbor	Lower Monumental	Little Goose	Lower Granite
Ammonia	81.3	59.6	64.3	75.7
Total Kjeldahl Nitrogen	1317.1	1146.1	1344.1	1746.5
Nitrate/Nitrite	0.7	0.6	0.7	1.4
Total Organic Nitrogen	1235.7	1086.7	1280	1671.3
Total Organic Matter (percent)	2.5	2.2	3.3	5.2
Phosphorus Bicarbonate	37.7	38.2	35	34.1
Sulfate	7.7	8.4	10.5	17.9
pH (standard units)	6.9	6.9	7.1	6.8

All results in mg/kg otherwise noted
Ice Harbor Dam - Lake Sacajawea
Note:
Lower Monumental Dam - Lake West
Little Goose Dam - Lake Bryan
Lower Granite Dam - Lower Granite Lake

3.3.5 Elutriate Fraction

For each of the sediment samples an ambient pH elutriate was prepared and analyzed for organophosphorus pesticides, organochlorine pesticides, metals, and nutrients, glyphosate, and AMPA. TPH and dioxin were not tested in the ambient pH elutriates. The purpose of the elutriate tests was to evaluate potential impacts to surface water quality from the resuspension of channel sediment. The elutriate tests were used to determine which inorganic or organic constituents would

preferentially partition by dissolution into the water and to determine their resulting aqueous concentration. The elutriate concentrations (maximum values) were then compared with applicable surface water quality standards to identify the Chemicals of Concern (CoC). The results of the laboratory analyses for the ambient pH elutriates, which are summarized in Tables 3-9 and 3-10, are presented in Normandeau, 1999b. Results include the number of samples analyzed, the number of samples above detection limits, the minimum value and maximum value detected, the arithmetic and geometric mean and the standard deviation for each parameter analyzed.

3.3.5.1 Organophosphorus Pesticides

The ambient pH elutriates were tested for the presence of organophosphorus pesticides, which as a group consist of 25 different organic compounds. The only organophosphorus pesticide detected was ethyl parathion, in one sample (LGO 8-4), at a concentration of 1.0 ppb (μg/l). Although identified in the one elutriate sample, ethyl parathion was not detected in any of the sediment samples. Parathion is a regulated substance in fresh waters in the states of Oregon and Washington with a maximum allowable concentration of 0.013 ppb (chronic).

3.3.5.2 Organochlorine Pesticides

No organochlorine pesticides were detected in any of the ambient pH elutriate samples. The organochlorine pesticides DDT (and its metabolites) aldrin, dieldrin, endrin, heptachlor and lindane had been detected in several of the sediment samples tested. The results of the elutriate tests suggest that although these compounds are present in the sediments they do not readily partition into water.

3.3.5.3 Glyphosate

Glyphosate was detected in only 2 of the 94 ambient pH elutriate samples, while AMPA was not detected. Glyphosate was detected at a concentration of 0.69 μg/L in a sample collected from Lake Bryan and at a concentration of 0.58 μg/L in a sample collected from Lake Sacajawea (Table 3-10). In comparison, the maximum contaminant level established for glyphosate by the USEPA in drinking water is 700 μg/L, well above the concentrations detected in the two elutriate analyses.

Table 3-10. Summary of Average Concentrations (ppb) of Organochlorine Pesticides and TPH in Sediment Collected during 1997 in the Lower Snake River

	Ice Harbor	Little Goose	Lower Granite	Lower Monumental	Average
4,4-DDD	ND	1.95	3.06	1.58	2.07
4,4-DDE	2.68	4.91	6.48	4.22	4.89
4,4-DDT	ND	1.64	1.72	1.56	1.62
Aldrin	0.75	0.84	0.87	0.82	0.83
Dieldrin	ND	1.74	ND	1.80	1.68
Endrin	ND	ND	ND	1.75	1.58
Lindane	ND	0.91	ND	0.90	0.85
TPH	67.63	45.86	58.25	49.15	55.41

ND = Not detected; average uses ½ of detection when concentrations < detection level.

3.3.5.4 Metals

Each of the 94 ambient pH elutriates were tested for the same suite of metals that were analyzed on their corresponding sediments. The results of the individual samples are summarized in a table

included in Normandeau, 1999b. For the 18 metals analyzed only beryllium, silver and thallium were not detected in the elutriate samples. Of these metals only silver was not detected in the original sediment samples.

The mean metal concentrations for the ambient pH elutriates are summarized by river reach in Table 3-11. The predominant metals detected include barium and manganese. The average concentration of barium, by river reach, in the ambient pH elutriates increases from 83.3 ppb for the samples collected from Lower Granite Lake to 243.6 ppb for the sediment samples collected from Lake Sacajawea. Although a corresponding trend in the concentration of barium in the sediment samples was not observed, it was one of the predominant metals detected. Its relatively high concentration in the ambient pH elutriates is most likely the result of its concentration in the sediments and its relatively high solubility in water (Hem, 1989).

Table 3-11. Summary of Mean Metal Concentrations for Ambient pH Elutriate Samples Collected during Phase 2 (1997) of the Lower Snake River Project

Metal (ug/L)	Ice Harbor	Lower Monumental	Little Goose	Lower Granite
Arsenic	3.9	2.6	2.2	1.8
Barium	243.6	197.5	140.9	83.3
Beryllium	ND	ND	ND	ND
Cadmium	ND	ND	0.1	ND
Chromium	0.6	0.8	0.4	0.6
Cobalt	0.5	1.2	0.4	0.5
Copper	2.9	3.2	3.2	4
Lead	ND	0.1	0.1	0.1
Manganese	861.5	1432.1	799.9	504.4
Mercury	ND	0.1	0.1	0.1
Molybdenum	3	3.5	3.8	2.2
Nickel	2.8	4.1	0.7	0.9
Selenium	2.3	1.2	0.3	0.3
Silver	ND	ND	ND	ND
Strontium	0.4	0.3	0.3	0.2
Thallium	ND	ND	ND	ND
Vanadium	2.1	1.2	1.8	1.5
Zinc	37.7	17.8	16.9	12.9

Ice Harbor Dam - Lake Sacajawea
Lower Monumental Dam - Lake West
Little Goose Dam - Lake Bryan
Lower Granite Dam - Lower Granite Lake

The predominant metal identified in the ambient pH elutriates was manganese (Table 3-10). The average concentration of manganese, by river reach, in the ambient pH elutriates ranged from 504 ppb for the samples collected from Lower Granite Lake to 1,432 ppb for the samples collected

from Lake West. In general, the trend in manganese concentrations in the ambient pH elutriate samples increases with distance downstream. As observed with barium, there does not appear to be a clear relationship between the concentration of manganese in the sediment samples and in the ambient pH elutriates.

The maximum metal concentrations detected in the ambient pH elutriates (Normandeau, 1999b) were also compared with the recommended surface water quality standards of the state of Oregon Department of Ecology, the United Nations (agricultural water quality goals), EPA, and WDOE to identify any CoC. The maximum concentration of four metals: arsenic, copper, manganese, and mercury were found to exceed their applicable water quality standards.

Because these metals also occur naturally in the environment, their concentrations were compared with representative background values to determine if they represent a CoC. The results of the ambient pH elutriate tests were compared with historical water quality data collected by the USGS from the Snake River near Anatone, Washington. The maximum detected concentration of arsenic, copper, and mercury were found to be less than their average background concentrations and as a result were not considered to represent CoC.

3.3.5.5 Nutrients

The ambient pH elutriate samples were also analyzed for the following nutrients: ammonia, nitrate/nitrite, phosphate, sulfate and TKN (Normandeau, 1999b). The mean concentration of each of these nutrients for the four reaches along the lower Snake River are summarized in Table 3-12.

Table 3-12. Summary of Mean Nutrient Concentrations for Ambient pH Elutriate Samples Collected during Phase 2 (1997) in the Lower Snake River

Parameter (mg/l)	Ice Harbor	Lower Monumental	Little Goose	Lower Granite
Ammonia	3.6	2.5	2.6	3.6
Total Kjeldahl Nitrogen (TKN)	8.8	5.7	4.1	6.2
Nitrate/Nitrite	0.2	0.2	0.3	0.4
Phosphate	0.1	0.1	0.1	0.1
Sulfate	19.6	17.9	26.9	29.7

Note:
Ice Harbor Dam - Lake Sacajawea Lower Monumental Dam - Lake West
Little Goose Dam - Lake Bryan
Lower Granite Dam - Lower Granite Lake
* - pH Dependent, Not Available
P - Proposed

The dominant form of nitrogen found in the elutriate samples was ammonia, which also was also the predominant form of nitrogen identified in the sediment samples. The dominance of ammonia may reflect the limited oxygen environment of the channel bed sediments as a result of the decomposition of organic material. The consumption of oxygen by the decay of organic material would lead to the reduction of nitrate/nitrite, thus limiting their concentrations in both the sediment and elutriate samples.

3.4 Primary Productivity/Food Web Complex

Biological productivity data also were collected throughout the study area as part of the recent sampling efforts. These biological productivity data were collected at both impounded and free-flowing reaches within the study area to compare differences between the two types of aquatic environments and to evaluate whether this data may be useful in predicting changes in biological productivity under the proposed drawdown and flow augmentation alternatives. Aquatic plant growth, particularly algae, which convert sunlight into energy, represent the primary producers in aquatic systems. Aquatic plants generally fall into three major categories: phytoplankton, attached benthic algae (ABA), and macrophytes. Phytoplankton refers to free-floating or suspended algae in the water column. Attached benthic algae refers to unicellular and filamentous forms of algae that attach to rocks and other hard substrate in water depths where sunlight penetrates to the bottom (i.e., photic zone). Both ABA and phytoplankton represent the base of the food chain and are an important food source for zooplankton, benthic animals (i.e., crayfish, amphipods, oligochaetes), aquatic insects, and benthivorous fishes. Chlorophyll *a* is often used as an indirect measure of phytoplankton and ABA biomass, because it is generally highly correlated with algal biomass. Macrophytes consist of the larger rooted plants that grow in shallow water, typically up to 2 meters in depth, along the shorelines of lakes and back-water areas. Although macrophytes are less important as a food source, they provide important shelter areas for insects as well as fish. Additionally, macrophytes help stabilize shorelines by reducing flow velocities and they also recycle nutrients through plant uptake.

Other biological productivity data collected included the sampling of zooplankton and macroinvertebrates. Zooplankton are tiny, floating animals that feed principally on algae and are an important food source for larger aquatic organisms such as snails and small fish (Wetzel, 1983). Data collection for macroinvertebrates was conducted at a limited number of sites throughout the study area.

The existing food web in the lower Snake River is driven by phytoplankton primary producers, with small contributions from attached benthic algae (Figure 3-32). Zooplankton compose the primary herbivore population; they in turn are consumed by planktivorous or plankton-eating fish. Aquatic insects are of lesser importance and are a food source for bottom-feeding fish. Piscivores, organisms that eat fish, form the top of the food web.

3.4.1 Chlorophyll *a*

Chlorophyll *a* concentrations measured from samples collected at various sites during the growing season between 1994 and 1997 did not display any clear patterns of increasing or decreasing levels (see Table 3-13). However, data collected during the 1997 growing season were highly variable both temporally and spatially. Although not universal for all stations, the highest seasonal chlorophyll *a* levels were generally observed in June and were associated with an abundance of diatoms. Figure 3-33 illustrates the seasonal changes in chlorophyll *a* levels for selected stations within the study area. There appears to be no distinct differences in the chlorophyll *a* levels between the Snake and Columbia river systems. Both the upstream Snake River station (SNR-148) and the

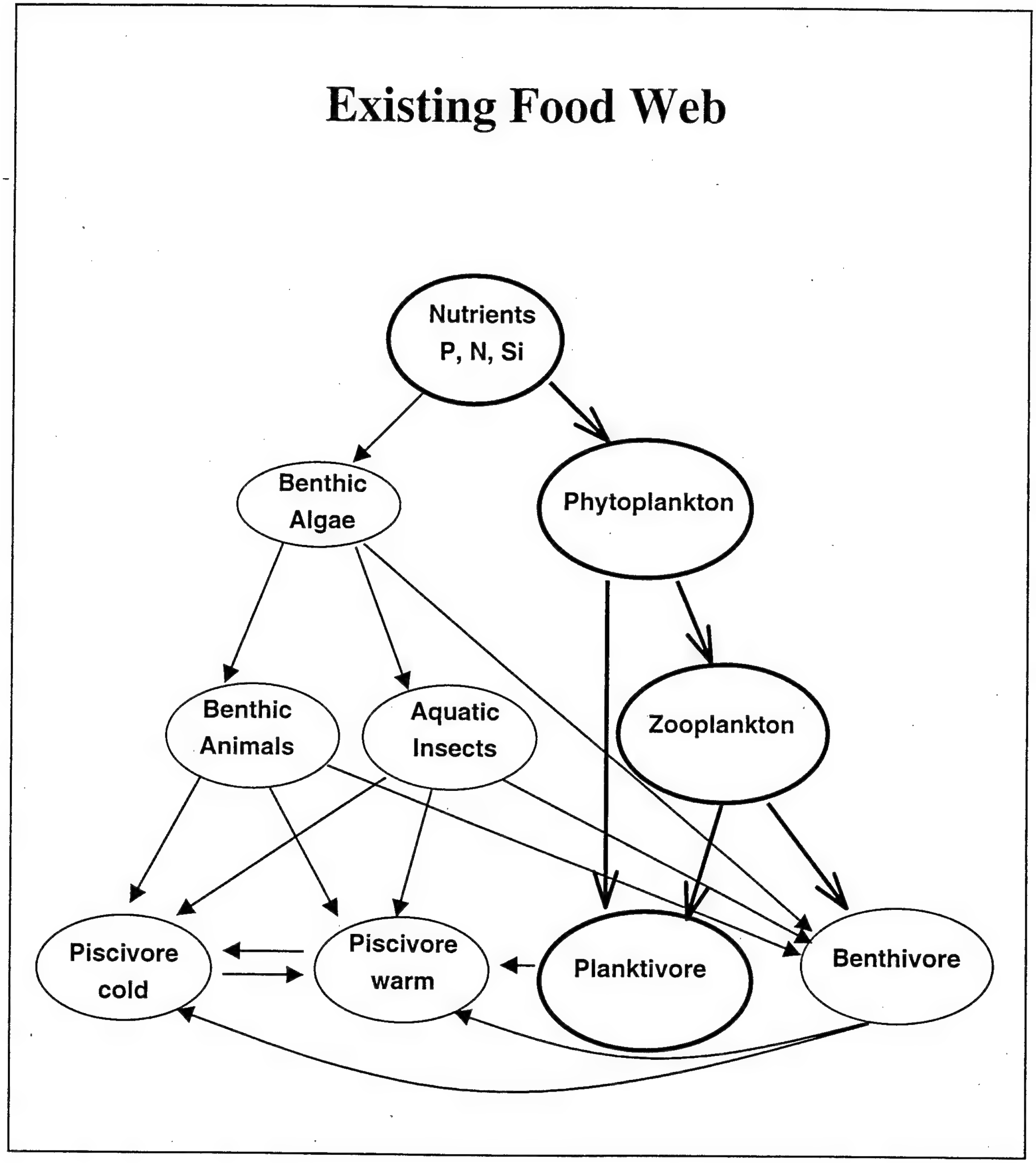


Figure 3-32. Generalized Food Web, Normalized Snake River

Table 3-13. Average and 95 Percent Confidence Intervals for Growing Season Chlorophyll *a* Concentrations (μg/L) in the Surface Water at Selected Sampling Sites and Years

Site	1994		1995		1996		1997	
	Avg	CI	Avg	CI	Avg	CI	Avg	CI
SNR-18		3.1		1.5		3.7		3.1
	7.8		3.8		8.7		5.6	
		12.6		6.1		13.6		8.2
SNR-83		4.0		-2.0		4.2		5.8
	6.2		8.5		9.1		7.9	
		8.4		18.9		13.9		10.0
SNR-108		2.4		2.9		8.0		6.3
	6.0		7.8		11.4		8.1	
		9.6		12.7		14.9		9.9
SNR-118		1.7		3.0				5.2
	7.7		7.0		ND	ND	6.8	
		13.8		11.1				8.4
SNR-129		4.7		4.6		6.6		5.3
	9.7		6.0		8.7		8.6	
		14.7		7.5		10.8		12.0

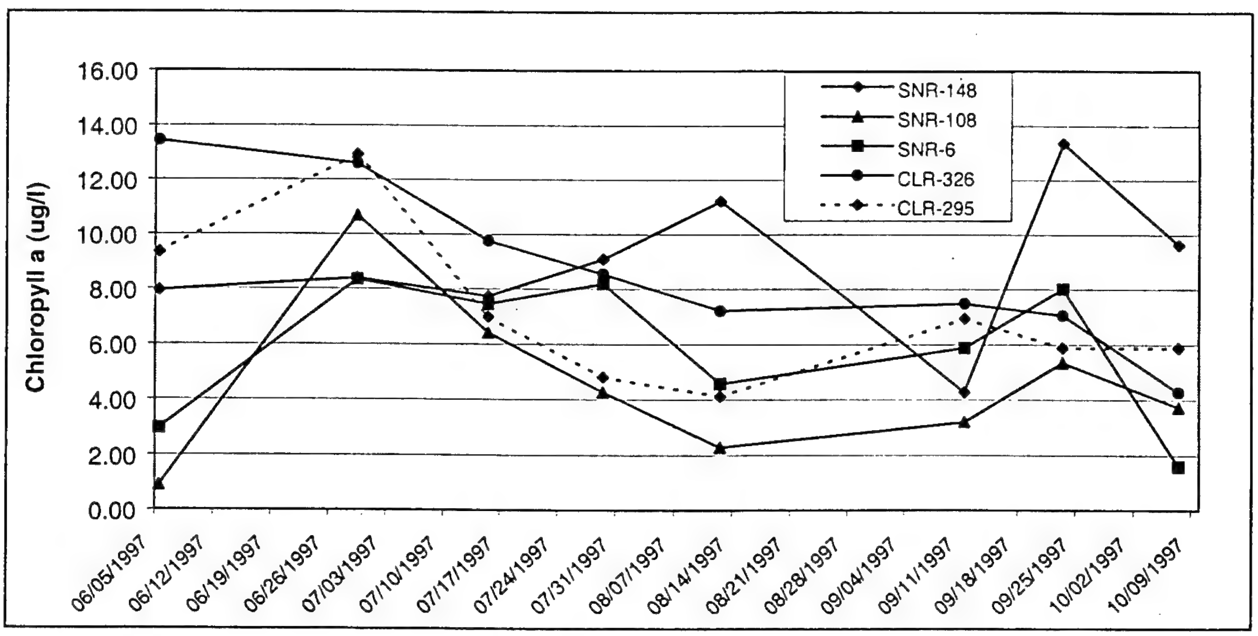


Figure 3-33. Chlorophyll *a* for Selected Sampling Stations in 1997

McNary Reservoir station (CLR-295) had similar peak levels in June, which is in contrast to most other parameters.

Previous research suggests that average chlorophyll *a* levels above 5.0 and 14.5 μg/l are indicative of mesotrophic and eutrophic conditions, respectively. Chlorophyll *a* levels will typically range between 3.0 and 11.0 μg/l and 3.0 and 78.0 μg/l for mesotrophic and eutrophic conditions, respectively (Wetzel, 1983). Based on the data presented in Table 3-12, concentrations of chlorophyll *a* generally are between the criteria for mesotrophic and eutrophic, with an average concentration between 3.8 and 11.4 μg/l, and an upper confidence interval (95 percent) of 18.9 μg/l for the period between 1994 and 1997.

Based on estimated median concentrations for 1997, Station SNR-108, in the Lower Granite Reservoir, had the highest median chlorophyll *a* level of 8.74 μg/l, and a mean concentration of 8.1 μg/l. In the Snake River, there was a general progressive decline in levels moving downstream with the seasonal median level for Station SNR-18 in the Ice Harbor Reservoir at 3.2 μg/l (and a mean concentration of 5.6 μg/l). The opposite was true in the Columbia River where the median concentrations appeared to increase downstream. The median concentration at the upstream station (CLR-397) was 6.72 μg/l and gradually increased to 8.01 μg/l at Station CLR-295 in the McNary Reservoir. Given the relatively low chlorophyll *a* levels measured at Ice Harbor, it is unclear as to whether the increase in the Columbia River is attributable to inputs from the Snake River.

3.4.2 Phytoplankton

Phytoplankton are the most important primary producer in the lower Snake River. The foundation of the food web, they transform light and nutrients into energy for herbivores such as zooplankton, which in turn support higher trophic levels. Phytoplankton grows best in low velocity waters with warm temperatures and high nutrient availability, particularly phosphorus. Phytoplankton growth is generally limited in stream or riverine systems, which have much greater flow velocities. In evaluating phytoplankton data, a relative increase in species diversity or richness under similar habitat conditions is often considered a positive indication of improving ambient water quality conditions. In contrast, the dominance of certain robust species, such as some species of blue-green algae, can often be indicative of poor water quality conditions. To evaluate the importance of phytoplankton as a food source, the volume or quantity of algae available for consumption is often the most critical parameter to be considered. For this reason, phytoplankton data is typically expressed in terms of overall biovolume (i.e., μm^3/mL) or population densities (i.e., cells/mL) as well as species composition.

Assemblages throughout much of the study area were quite similar through 1997, showing a peak in overall density during the last week of June and early July, followed by a decline through mid-to-late summer and a secondary peak in autumn. The lower Snake River reach generally had the highest peak densities ranging from 1303 cells/mL at SNR-108 to 2842 cells/mL at Station SNR-6. The corresponding biovolumes for these peak densities are 1,133,792 and 1,749,869 μm^3/mL for Stations SNR-108 and SNR-6, respectively. Peak algal densities for the Columbia River stations ranged from 1516 to 1832 cells/mL with corresponding biovolumes of 699,846 to 879,791 μm^3/mL at Stations CLR-369 and CLR-295, respectively. The Clearwater River at Station CLW-11 had a relatively low peak density of 749 cells/mL and a biovolume of 321,077 μm^3/mL during the same time period.

There were few differences in the number and types of phytoplankton observed at the impounded pool sites above dams and transitional sites below dams within the lower Snake River system. For most of the study area, diatoms (Bacillariophyta) were typically dominant throughout much of the season, but especially during the peak flow period. At this time, diatoms typically accounted for more than 90 percent phytoplankton biovolumes. The cryptophytes (*Rhodamonas minuta* and *R. m. nanoplanctica)* became dominant or co-dominant (by numerical density) at most sites in the lower 50 miles of the Snake River during the second half of the season. However, because of their small size, they comprised a relatively small fraction of assemblage biovolume. Phytoplankton blooms (dominated by the genus *Aphanizomenom* and *Anabaena*) do occur in the lower Snake River Reservoirs. These blooms are typically brief, lasting only a few weeks, but significant in their total community dominance during that time period and potential subsequent impacts on oxygen concentrations and invertebrate food supply. There have been documented occurrences of surface scum resulting from these taxa. Research has noted much littoral detrital accumulation from senescing planktonic algae blooms during the later summer that deposits on attached benthic algal communities. This senescing planktonic algae likely provides a significant late-summer nutrient input to the attached benthic algal communities, as well as a direct food source for littoral benthic macroinvertebrates.

Other commonly observed taxa within the lower Snake River Reservoirs include the diatoms *Melosira islandica* (18.3 percent of the total collection), *Cyclotella meneghiniona* (11.7 percent) and *Fragillaria crotenensis* (11.3 percent), and the cryptophytes *Rhodomonas minuta* (7.3 percent) and its variant *R. m. nanoplanctica* (14.4 percent). Few other taxa exceeded 2 percent of the total collection except the diatom species *Asterionella formosa* (4.5 percent) and *Melosira granulata* (3.7 percent), diatoms of the genera *Diatoma* (5.3 percent) and *Synedra* (3.4 percent), the green algal genus *Scenedesmus* (2.3 percent), and the blue-green *Anabaena* spp. (4.3 percent).

Similarly, there was very little difference in the phytoplankton assemblage at the upstream, free-flowing Snake River station (SNR-148) as compared to the impounded Snake River locations. The free-flowing Snake River assemblage was essentially similar to those downstream in Lower Granite Reservoir, except for having higher densities of diatoms early in the year and lower densities of cryptophytes on most occasions. These minor differences may be due in part to the higher-than-normal flows that occurred in 1997, which reduces the hydraulic residence time and limits algae growth in the impoundments.

The Clearwater River phytoplankton assemblage differed somewhat from Snake and Columbia River assemblages in that blue-green algae *Oscillatoria* and *Anabaena* dominated throughout much of the sampling season. Blue-green algae peaked in abundance from mid-July to mid-September. During this time period, blue-green algae accounted for 28.5 to 85 percent of the cell densities and 29 to 48 percent of the sample biovolume. Outside of this period, the blue-green algae accounted for less than 5 percent of the total biovolume.

3.4.3 Attached Benthic Algae

Attached benthic algae are a secondary source of primary productivity in the lower Snake River. As algae that are attached to rocks and other hard substrate, they provide a food source for benthic organisms such as aquatic insect larvae, amphipods, and oligochaetes. The 1997 empirical data on ABA were based primarily on measurements of chlorophyll *a* concentrations samples collected from tile and mylar subtrates placed in the field for a 14-day incubation period. Mean concentrations

(mg/ m^2) of five "species" of photosynthetic pigments (evaluated from tile substrates) were reported including chlorophyll *a* (mono-and trichromatic), b, and c, and phaeophytin.

The upstream station (SNR-148) had consistently high values of the chlorophyll *a* throughout the season ranging from 29.06 to 93.6 mg/m^2 with the highest value occurring in October. Only the downstream station in the Ice Harbor Reservoir (SNR-18) had chlorophyll *a* values that were higher, which were frequently above 100 mg/m^2 from July through early September. In the Lower Granite Reservoir (SNR-118), the ABA chlorophyll *a* values ranged from 23.04 to 73.35 mg/m^2, which are generally lower than that recorded at the upstream station SNR-148.

Trichromatic chlorophyll *a* levels (the measure of chlorophyll used in the 1975 and 1976) EPA surveys of Falter et al. (1976) measured in the high-flow year 1997 at the free-flowing SNR-148 were in the 30-100 mg/m^2 range at 1.5 m depth. In the low-flow 1998, the range was 60-110 mg/m^2 at 1.5m depth. The ABA trichromatic chlorophyll *a* levels obtained in 1975 and 1976 at this site were 10-20 mg/m^2. There was essentially no overlap between the ranges of 1976 and 1997-98. The earlier data are from glass-slide incubations while the later data are from a combination of natural rock, tile, and a mylar substrate. Even though substrates were different, these ABA data over the 24-year time spread are probably one of the better indicators available of increasing productivity of the Snake River coming into the project area over this time period.

The mean biomass, as measured by the ash-free, oven dry weights (AFODW), for the attached benthic algae samples collected in 1997 follows a similar pattern with the Ice Harbor Reservoir station (SNR-18) having highest biomass of 10.94 to 37.09 g/m^2. The AFODW for the Lower Granite Reservoir samples (SNR-118) ranged from 9.09 to 25.25 g/m^2. Samples from the upstream lower Snake station (SNR-148) had ADOFWs ranging between 4.39 and 15.17 g/m^2. Historical data indicate that ABA ash-free biomass in 1976 averaged 1.64 g/m^2 at SNR-148. In contrast, the results from 1997, when samples collected from a comparable depth and time period and a non-silt collecting mylar substrate, averaged 6.65 g/m^2, and in 1998 7.95 g/m^2. The different measure of ABA ash-free biomass further suggests that productivity in the lower Snake River is increasing.

AFODW samples collected from the upper McNary Reservoir (CLR-326) had AFODWs ranging from 2.26 to 30.27 g/m^2 with the highest level occurring later in the season toward the end of September. Samples collected in the free-flowing Hanford section (CLR-369) had relatively low biomass values with AFODWs for most samples below 6.0 g/m^2 and a seasonal range of 0.64 to 14.09 g/m^2. The McNary Reservoir and the lower Snake River Reservoirs apparently produce a considerable amount of attached benthic algae biomass along the littoral and shoreline areas. However, much of the system has accumulated fine sediments, which limit the amount of ABA and epilithic periphyton. This finding may prove interesting in evaluating the proposed natural river drawdown alternative, because ABA is generally more prolific in riverine conditions rather than in a reservoir environment. As discussed earlier, deep-water releases from the Dworshak Dam were started in 1994 in conjunction with releases for fish flow augmentation to help lower downstream temperatures in the lower Snake River in July and August.

3.4.4 Primary Productivity

Primary productivity is a measure of the amount of carbon per unit time produced by all aquatic plants. As primary producers form the base of the food chain, the level of primary productivity ultimately dictates the productivity of the entire ecosystem. The number of primary productivity

data points available from the mid-1970s are limited. SNR-18 in 1976 was the most complete, while the other stations typically had at most one or two determinations per year, and thus were not used to construct Tables 3-14 and 3-15. The general pattern was for greater pelagic primary productivity in 1994 when discharge was low and hydrologic residence times were maximized. Productivity decreased in 1995 when discharge increased, with what appears to be an exception at Central Ferry (SNR-83). The reason for the apparent increase in productivity was one sample day in late August when the rate was unusually high, thus skewing the distribution.

Table 3-14. Average and 95 Percent Confidence Intervals for Growing Season Primary Productivity Rates (mgC/m^3/hr) at 1 m for Selected Sampling Sites and Years

Site	1975		1976		1977		1994		1995		1996		1997	
	Avg	CI	Avg	CI	Avg	CI	Avg.	CI	Avg	CI	Avg	CI	Avg	CI
SNR-18	ND	ND	14.1	-0.4 28.6	ND	ND	44.8	23.3 66.4	14.9	11.0 18.8	ND	ND	23.8	16.0 31.6
SNR-83	ND	ND	ND	ND	ND	ND	35.6	5.9 65.3	62.3	-15.3 139.8	ND	ND	27.9	14.4 41.5
SNR-108	ND	ND	ND	ND	ND	ND	77.1	25.2 128.9	42.9	19.1 66.8	ND	ND	ND	ND
SNR-118	ND	ND	ND	ND	ND	ND	77.2	20.4 134.1	20.4	< 1.0 41.3	ND	ND	23.7	21.2 26.2
SNR-129	ND	ND	ND	ND	ND	ND	67.4	25.2 109.6	23.6	12.5 34.8	ND	ND	ND	ND

Table 3-15. Average and 95 Percent Confidence Intervals for Depth-Weighted Growing Season Primary Productivity Rates (mgC/m^3/hr) for Selected Sampling Sites and Years

Site	1975		1976		1977		1994		1995		1996		1997	
	Avg	CI	Avg	CI	Avg	CI	Avg	CI	Avg	CI	Avg	CI	Avg	CI
SNR-18	ND	ND	ND	ND	ND	ND	29.9	16.2 43.5	9.6	7.1 12.0	ND	ND	15.7	9.7 21.7
SNR-83	ND	ND	ND	ND	ND	ND	25.3	9.2 41.4	34.0	-5.1 73.0	ND	ND	17.3	10.1 24.6
SNR-108	ND	ND	ND	ND	ND	ND	49.2	22.7 75.8	27.1	12.2 42.1	ND	ND	ND	ND
SNR-118	ND	ND	ND	ND	ND	ND	45.9	9.3 82.4	14.0	0.0 28.5	ND	ND	14.4	12.4 16.4
SNR-129	ND	ND	ND	ND	ND	ND	39.5	17.4 61.6	14.5	8.2 20.8	ND	ND	ND	ND

3.4.5 Zooplankton

Zooplankton are an important source of food for plankton-eating fish, which in turn are consumed by other fish. Zooplankton assemblages are also expressed in terms of total biomass, population densities, or species composition. Species composition is usually determined first through enumeration and identification of the various organisms in a sample. Total biomass is then calculated through established length/width relationships for each species type. Zooplankton data were analyzed with the same techniques described for phytoplankton. Time series graphs of density estimates were plotted for each location using totals for three major taxonomic groups: rotifers, copepods, and cladocera. Throughout the season, the highest densities of zooplankton were generally observed in the lower Snake River Reservoir sites and in the two McNary Reservoir sites (CLR-306 and CLR-295). The transition sites in the upper McNary Reservoir (CLR-326) and the Lower Granite Reservoir (SNR-118 and SNR-129) generally had lower and somewhat more variable densities. The same was true for the free-flowing Snake (SNR-140 and SNR-148) and Clearwater River sites (CLR-11). However, densities were quite high early in the season at the upstream riverine Snake River site (SNR-148), but dropped sharply thereafter. Densities and taxonomic composition through time in the free-flowing Hanford Reach (CLR-369) were quite similar to what was found farther upstream in Priest Rapids Reservoir (CLR-397).

Over the entire study area, the 1997 zooplankton assemblage was composed of 30 nominal taxa, distributed fairly equally among members of the phylum Rotifera and two major groups of microcrustacea, Copepoda and Cladocera. This total included at least 9 species of cladocerans, 4 species of copepods, and 11 species of rotifers. At most locations, rotifers were most abundant early in the season, then tapered off in density later in the sampling season. However, the number of different species (i.e., taxa richness) at most locations varied considerably between sampling events. Over the entire season, total zooplankton richness seems to depend mostly on the reach type, with reservoir sites supporting the most taxa and riverine sites supporting the fewest. Reservoir and transition sites usually supported between 7 and 16 individual taxa, while riverine sites on the Snake and Clearwater rivers supported no more than eight taxa at any given time. The Hanford Reach, CLR-369, had the greatest variability with anywhere between 1 and 11 taxa identified depending on the sampling event.

In decreasing order of system-wide abundance, taxa that occurred at a mean density of ≥ 0.1 individuals/L (averaged over all sites and times) included the cladoceran *Daphnia retrocurva*, cyclopoid copepods, the copepod *Diacyclops thomasi*, the cladoceran *Bosmina longirostris*, copepod nauplii, and the rotifer *Keratella cochlearis*.

3.4.6 Benthic Macroinvertebrates

Benthic macroinvertebrates are an important link in the food web between primary producers and secondary consumers such as bottom feeding fish and large invertebrates, which consume benthic macroinvertebrates. The most recent benthic macroinvertebrate data consist of data collected in 1994 and 1995 from three locations in Lower Granite Reservoir on the Snake River. The three locations sampled include the Offield site in the lower portion of Lower Granite Reservoir, an artificial shoal-dredge disposal area in mid-reservoir called Centennial Island, and the Silcott Island site, a large island/backwater complex located a few miles downstream of Lewiston-Clarkston within the upper third of the reservoir. Sampling methods involved use of an aerial sampler that enabled a spatial density measurement of the number of organisms per square meter of bottom area.

Samples were collected at approximately monthly intervals from March 1994 through October 1995. Separate grabs were taken at depths of 3, 9, and 18 meters from each location. A total of 42 nominal taxa of benthic macroinvertebrates were collected in 1994-1995 at the three different locations. Generally, a greater variety of taxa were observed at the shallower depths (3 and 9 meters). Some organisms were identified to species, but many taxa were lumped into broad taxonomic categories (e.g., Bivalvia). Oligochaete worms were numerically dominant at all three stations in both years, but were particularly abundant at Silcott and Centennial Islands. Chironomids were second in abundance at all three sites, and actually exceeded densities of oligochaetes on a few occasions at the Offield site. These two groups comprised 82-97 percent of the total collection from each station. Bivalve mollusks comprised nearly 12 percent of the collection at Offield, but made up < 2 percent of the collection elsewhere.

4. Alternative Analysis

4.1 Overview of Available Data Sources

This section describes the various alternatives being evaluated to improve juvenile salmon migration and the potential water quality impacts that may result from these alternatives. The discussion of potential impacts focuses primarily on the those parameters that may have some effect on anadromous fish and/or those parameters that are likely to be most affected by the proposed drawdown alternatives. The additional flow augmentation and the natural river drawdown alternative obviously have the potential to change flow and other hydrologic conditions and, thus, water quality. In addition, the proposed TDG improvements and changes in the Corps spill regime could also affect water quality, particularly dissolved gas saturation levels. The potential impacts associated with these alternatives are evaluated for both short-term or transition-period construction effects and long-term operational effects. The major system improvements pathway focuses on optimizing the fish bypass collection and transportation systems and is not be expected to produce discernable changes in water quality conditions.

The environmental, economic, social, cultural, and recreational effects of four flow augmentation alternatives (no augmentation, 427 MAF, and two schemes for 1.427 MAF) were analyzed by the Bureau of Reclamation (BOR 1999). The analysis was restricted to the Snake River System upstream of Lower Granite Dam and, thus, is applicable to this study as information concerning regional impacts that focus on the lower Snake River. The report indicates upstream effects would include reduced volume, which in turn would increase concentrations of nutrients, suspended sediments, and fecal coliform bacteria and would reduce dissolved oxygen. Spring turnover would likely occur earlier in the season, leading to increased mixing. The location of these effects would depend on the source of water for augmentation. Downstream effects, including the lower Snake River, would include higher water volume and river, which would reduce concentrations of nutrients, suspended sediments, and fecal coliform bacteria and would increase DO and TDG concentrations.

Predictions of future water quality conditions are based on the results of water quality and sediment modeling using data collected mainly from 1994 through 1997, as well as two other recent modeling studies (Perkins and Richmond 1999, Yearsley 1999). Extensive water quality data were collected from 1994 through 1997 in the lower Snake system (Normandeau 1999a) to evaluate changes in biology and water chemistry associated with proposed dam breaching (Normandeau 1999a). Parameters were selected in order to support the modeling effort, and included physical (transparency, conductivity, temperature), chemical (nutrients, dissolved oxygen, anions and cations, pH, and alkalinity) and biological (chlorophyll *a*, biochemical oxygen demand, primary productivity, and zooplankton biomass) parameters.

These data were used in a modeling effort, which relied upon the WQRRS model to simulate future changes in biological productivity as well as temperature and water quality under the proposed normative "free-flowing" condition (Normandeau 1999a). Few data describe the limnology and biological productivity of the lower Snake River system during the period prior to the closure of the four hydroelectric and navigation dams in the 1960s and 1970s. Those data that are available have limited utility in predicting water quality in the future if the dams were breached and the river was

returned to its normative state. Water quality conditions in the watershed have changed markedly over the intervening years because of changing irrigation withdrawals, timber harvest practices, and wastewater treatment improvements, and as a result, water quality prior to impoundment will not likely approximate water quality to be expected in the normative river. Water quality modeling is the only practical way to predict what water quality can be expected if the dams on the lower Snake were breached and to compare alternatives for managing the normative river system.

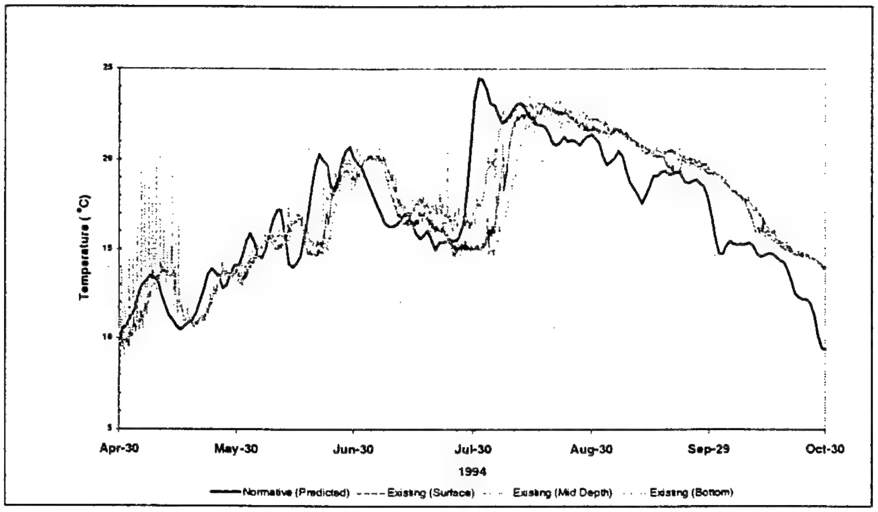
The WQRRS model of the drawdown alternative was built and calibrated using bathymetric and hydraulics data from 1934 and temperature data from the 1950s prior to damming. The model assumes that the post breaching river will have physical characteristics similar to the river in 1934. The hydraulic computations for the model were completed using the Modified Pulse method which provides a stable solution even with high water velocities and is relatively simple compared with the other available methods. Then this model was applied to calendar years 1994, 1995, and 1997 using the actual hydrologic, meteorologic, and inflow water quality data from those years as input. Data from 1994 were used to represent a dry year, 1995 to represent an average year, and 1997 to represent a wet year. Based on mean annual flows measured in the Clearwater River at Spalding and the Snake River at Anatone, 1997 ranked as the highest flow year of record, 1994 ranked near the lowest 10 percent of flows, and 1995 was slightly wetter than normal. Water year 1997 was abnormally wet all year. Water year 1994 was dry during the May-June snowmelt period and during the August-October low-flow period. Water year 1995 followed the historical mean monthly flow pattern quite well except in August and September when flows were wetter than normal. Model predictions of primary and secondary productivity from the 1997 simulation were then compared to actual field data from that year, where data were available. The existing system with the dams in place was not modeled during this effort.

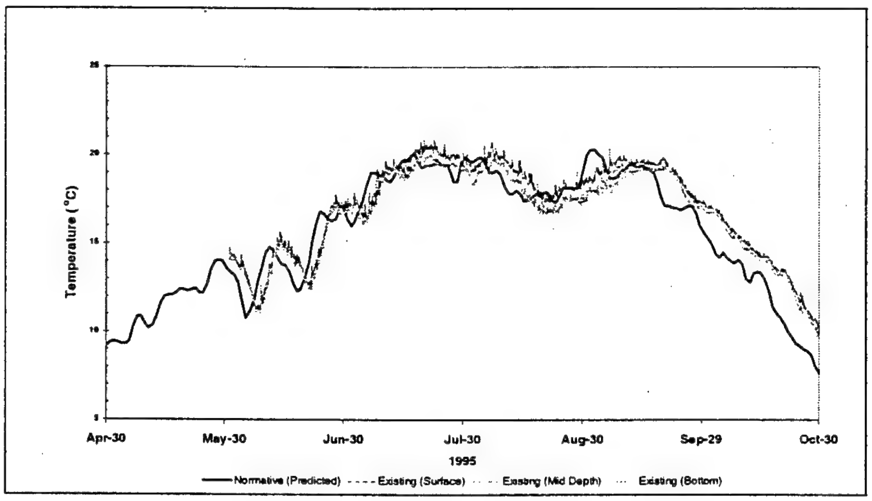
The WQRRS modeling results are best used on a relative basis for comparing flow and hydraulic and nutrient loading scenarios rather than as a definitive predictive model for several reasons. First, the biological data available to calibrate and verify the model were limited. Second, the base case scenario for the modeling assumes a steady-state system some years after breaching and after the sediments behind each dam have been either redistributed or stabilized. The model assumed that the stream channel remaining after the redistribution of sediments would be similar to that which was present in the system in 1934, the last pre-dam year when there were extensive bathymetric data collected on the system.

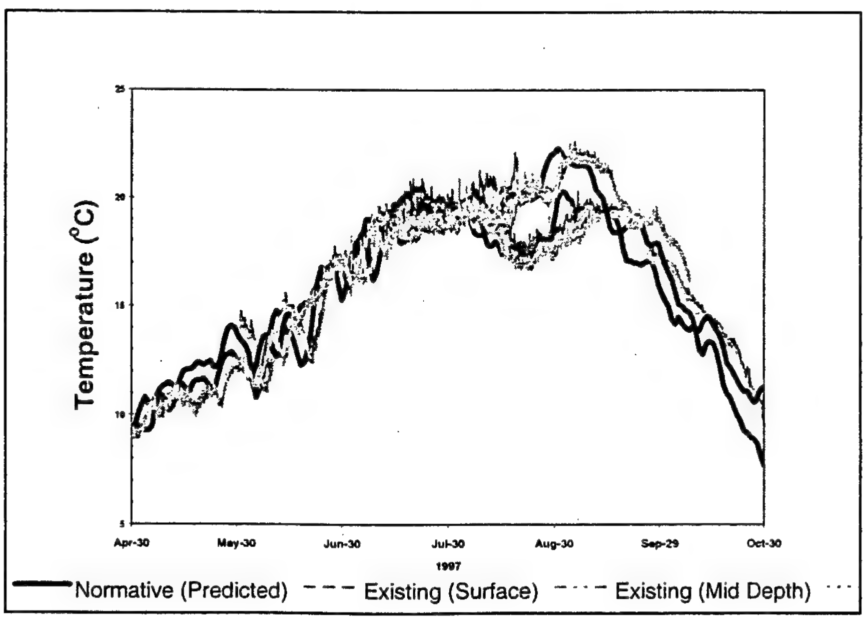
The WQRRS modeling effort did include "normative" river temperature simulation for the years that biological productivity simulations were completed (1994, 1995, and 1997, Figure 4-1). However, these temperature predictions were not the primary objective of the study and were included to provide a picture of the seasonal patterns of temperatures that govern many of the biological processes that contribute to total primary and secondary productivity. The temperature predictions are nonetheless useful in providing a comparison of the seasonal temperature regime among 3 years with very different hydrometeorologic conditions.

The objective of the WQRRS modeling effort was to simulate total primary and secondary productivity as an indication of the food sources available for higher trophic levels, which include salmon and steelhead. Predictive modeling of the standing crop of individual species was not the intent of the modeling. The currently available data for the food web of the lower Snake River are

Figure 4-1. 1994, 1995, 1997 Normative and Existing Water Temperatures at Site 5, River Mile 110.5







insufficient to support such an effort for the entire system. Some of the trophic levels as simulated were split into functional groups based on similar feeding and physiological characteristics. The food web presented in Figure 3-28 presents the general representation of the system used by the model. When the food web is represented with simplified ecological relationships, the contribution of salmon and steelhead to the sum of the productivity in the fish community is very small. Salmon and steelhead dynamics and productivity are much better represented by bioenergetics models such as the CRiSP 1.5 model discussed in other appendices of this EIS.

EPA has recently developed a temperature model of the Columbia System to support a total maximum daily load (TMDL) for temperature as required under Section 303(d) of the Clean Water Act (Yearsley 1999). The model utilizes a thermal budget approach similar to the full heat budget method used in the WQRRS modeling effort referenced above, but uses a mixed Eularian-Lagrangian solution method. Three scenarios were examined for the lower Snake portion of the system. The first scenario incorporated the existing configuration of dams, hydrology and meteorology from 1975 to 1995, and tributary temperatures estimated from the 21-year meteorologic record. The second scenario assumes that all of the dams are removed and uses the same hydrometeorologic record as scenario 1. The third scenario is similar to scenario 1 except that tributary temperatures are not allowed to exceed 16° C.

A modeling study completed by the Pacific Northwest Laboratory (Perkins and Richmond 1999) used MASS1 (Modular Aquatic Simulation System 1D), a one-dimensional hydrodynamic and water quality model to predict water temperatures on the lower Snake River for the period 1960 through 1995. This period includes a period prior to the construction of the dams, the construction period, and the present period with all four dams in place.

To assess the potential impacts from sediment transport associated with each of the alternatives under consideration, a study of existing sediment quality was conducted. The results of this study were summarized in previous sections of this report and were used to model the transport of sediment and its impacts on water quality, as discussed in later sections. Sediments were collected in areas where fine sediments are likely to accumulate following drawdown and analyzed for potential contaminants. Elutriate analyses were also conducted to ascertain likely transport into the overlying water column. CoCs were selected based on comparisons with known standards, and concentrations were examined at points of compliance, where exceedances might increase risks to biota and human health.

Empirical data recorded during the 1992 experimental Lower Granite Reservoir Drawdown Study also provide relevant information that can be used to extrapolate and predict potential changes resulting from the proposed drawdown condition. Although the proposed drawdown of all four reservoirs would be on a much larger scale than that conducted in the 1992 study, the information is most useful in describing potential water quality conditions during the short-term transition phase. During this study, the reservoir was drawn down 33 feet, which is much less than the approximately 100 feet of drawdown currently being proposed. Much of the relevant empirical data collected pertains to changes in flow velocities, sediment transport and turbidity levels as the Lower Granite Reservoir was being drawn down.

The results of the Columbia River SOR study are also relevant to this current assessment of future water quality changes, because the proposed natural river drawdown alternative was also considered in that study. As part of the SOR study, the potential effects of reservoir drawdown on natural river

elevations were evaluated with respect to total dissolved gas supersaturation, temperature and sediment movement. Erosion and sediment movement were major focal points of these studies. Various erosional processes such as bed scour and bank slumping were modeled using the HEC-6 model to simulate hydrologic conditions and the HEC-5Q model to predict water quality conditions. The SOR study differs from the current study in that the previous modeling effort included the entire Columbia River Basin and did not have the benefit of the recent water quality data collected since 1994. Furthermore, the SOR dam breaching scenario assumed a 4.5-month drawdown beginning in April of all four dams in one year. Finally, the SOR estimated approximately 7.1 million cubic yards of accumulated sediment in McNary Reservoir, 7-11 times less than the 50-75 million cubic yards currently estimated by the Corps' Hydrology Branch (Normandeau, 1999b, Appendix B). Therefore, SOR modeling results are best used as a relative comparison between alternatives rather than relying on absolute predictions of future conditions.

4.2 Description of Alternatives

Table 4-1 presents a summary of the various structural and operational modifications proposed under each of the alternatives selected for analysis to improve juvenile salmon downstream migration. The eight alternatives are grouped into three main alternative pathways including the existing system pathway, the major system improvements pathway and the natural river drawdown pathway.

The existing system pathway includes two alternatives; the existing condition alternative (Alternative A1) and a maximize transport alternative (Alternative A2). Alternative A1 consists of maintaining the existing structural configuration at each dam with some minor improvements that are already planned. These structural improvements would include new extended bar screens at the Ice Harbor and Lower Monumental dams, an upgrade to the Lower Granite Juvenile Facility System to enhance the fish collection and transport mechanisms, and other fish guidance efficiency (FGE) and gas abatement improvements at each of the dams. These improvements include the addition of end bay deflectors and modification of existing deflector elevations at Little Goose and Lower Monumental, and modification of all eight deflectors at Lower Granite. Modified deflectors are assumed at Lower Monumental and Little Goose. The current flow operations would be maintained as specified in the 1995 and 1998 Biological Opinions, including the 427 KAF (thousand acre-feet) flow augmentation. Flow augmentation is conducted in July and August using flow volumes from the upper and middle Snake River dams. The lower Snake River reservoirs would continue to operate at MOP levels during the out-migration period and spill releases will be provided to bypass juvenile salmon and steelhead.

Alternative A2 is very similar except the transport mechanisms would be enhanced to maximize the current fish transport systems. Voluntary spill releases would be eliminated except for non-collected smolts at Ice Harbor.

The second major pathway is referred to as the major system improvements pathway. All five major system alternatives (A2a, A2b, A2c, A6a, and A6b) incorporate major fish passage improvements. Alternatives A2a, A2b, and A2c would eliminate volunteer spills except at Ice Harbor for smolts and use the 1995/1998 Biological Opinions guidelines for spills. Alternative A2a would maximize fish collection by improving or installing surface bypass collection, similar to Alternative A2. The primary mode of downstream migration would be through fish collection and juvenile transport

Table 4-1. Lower Snake River Juvenile Salmon Migration Feasibility Study Alternatives Matrix

	Pathway Alternatives							
	Existing System		Major System Improvements					Drawdown
	Existing Condition	Maximize Transport	w/Maximized Transport	w/Minimized Transport	w/Adaptive Management	w/In-river Migration and Additional 1.0 MAF Flow Augmentation	w/In-river Migration and Zero Flow Augmentation	Natural River Drawdown
	A-1	A-2	A-2a	A-2b	A-2c	A-6a	A-6b	A-3
STRUCTURAL CONFIGURATION								
Navigation								
Current configuration	●	●	●	●	●	●	●	
No navigation								●
Hydropower								
Current configuration	●	●	●	●	●	●	●	
No hydropower								●
Planned Improvements								
LGR Juvenile Fish Facility	●	●	●	●	●	●	●	
Fish separator	●	●	●	●	●	●	●	
Cylindrical dewatering screens	●	●	●	●	●	●	●	
New trash shear booms	●	●	●	●	●	●	●	
Modify ESBS	●	●	●	●	●	●	●	
Major Dam Feature Replacement/Rehabilitation								
Turbines and generators	●	●	●	●	●	●	●	
ESBS and VBS	●	●	●	●	●	●	●	
Spillway gates	●	●	●	●	●	●	●	
Navigation gates	●	●	●	●	●	●	●	
Timber bumbers	●	●	●	●	●	●	●	
Valves	●	●	●	●	●	●	●	
Fish ladder pumps	●	●	●	●	●	●	●	
Facility roadways	●	●	●	●	●	●	●	
Major Fish Passage Improvements								
Surface Bypass Collector			●	●	●	●	●	
Behavioral guidance curtain					●			

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Table 4-1. Lower Snake River Juvenile Salmon Migration Feasibility Study Alternatives Matrix

	Pathway Alternatives							
	Existing System		Major System Improvements					Drawdown
	Existing Condition	Maximize Transport	w/Maximized Transport	w/Minimized Transport	w/Adaptive Management	w/In-river Migration and Additional 1.0 MAF Flow Augmentation	w/In-river Migration and Zero Flow Augmentation	Natural River Drawdown
	A-1	A-2	A-2a	A-2b	A-2c	A-6a	A-6b	A-3
Earthen Portion of Dams								
Remain intact	●	●	●	●	●	●	●	
Breached								●
OPERATIONAL REQUIREMENTS								
Flow Augmentation								
1995/98 biological opinion (427 KAF)	●	●	●	●	●	●		●
Upper Snake augmentation								
Additional 1.0 MAF						●		
Zero augmentation							●	
Spill								
1995/98 biological opinion	●	●	●	●	●	●	●	
Maximize volunteer spill						●	●	
No volunteer spill								●
Ice Harbor non-collected smolt spill		●	●	●	●			
Transport								
1995/98 biological opinion	●			●				
Maximize transportation/limited in-river migration		●	●					
No transportation/maximize in-river migration						●	●	
LSRFWCP Requirements								
Current operation	●	●	●	●	●	●	●	
Amended operation								●
Recreation Requirements								
Current operation	●	●	●	●	●	●	●	
Amended operation								●

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mechanisms. Below the dams, fish would be collected for transport or moved to the tailwater for in-river migration. Alternative A2b is the same, but would continue the transport according to the 1995/98 Biological Opinions. Alternative A2c would utilize the 1995/98 Biological Opinions guidelines for spill but not transport, and would incorporate as-yet-undeveloped technologies for fish passage structural improvements.

Alternatives A6a and A6b would maximize in-river migration without transport. End bay deflectors and modified deflectors would be added at Lower Monumental and Little Goose Dams; the latter would also be added at Lower Granite. Fish passage would be improved by dewatering the surface bypass collector. Alternative A6a would focus on maximizing in-river migration by optimizing additional spill releases during the migration period and increasing the existing flow augmentation by another 1 MAF by acquiring water withdrawal rights in the upper Snake River watershed. The current 427 KAF flow augmentation would also continue. Alternative A6b would eliminate the current flow augmentation and use only the 1.64 MAF established for the Snake River Basin in the original water budget developed by the Northwest Power Planning Council (NPPC).

The third major alternative pathway consists of only one alternative (Alternative A3), which involves permanently lowering the four lower Snake River impoundments to natural river elevations by breaching the earthen portion of each of the four dams. There are likely to be various options to implement this drawdown alternative including breaching all four dams in one year, breaching of two dams per year over two successive years or breaching of one dam per year for four years. The potential magnitude for short-term impacts is likely to be greatest with the breaching of all four dams in a one-year scenario, but they will occur over the shortest time period. For purposes of this assessment, it was assumed that two of the four dams would be breached in successive years over a two-year time period. Lowering reservoir water levels will initially occur through the use of reconfigured turbines and turbine passageways. The dam breaching process and the lowering of water levels to pre-impoundment elevations will be conducted during the eight-month period from August to March, when river flows are generally the lowest. The overall objective will be to maintain controlled flow patterns that are within the range of normal flow conditions to minimize erosion and water quality impacts. Extensive rip-rap placement is also anticipated for channel and bank stabilization as a new channel area becomes established along the 140-mile reach.

It is important to note that the process of implementing this drawdown is estimated to require eight to nine years starting with detailed engineering studies, geotechnical investigations, surveying and quarry development. Assuming this construction process began on January 1, 2001, the mid-point of construction would occur around 2005-2006.

Many refer to the proposed river system following dam breaching as the "normative" rather than "natural" river condition, because the flow through the lower Snake reach will still be regulated by upstream dams. Thus, the river will not revert back to its naturally free-flowing flow regime that occurred historically during the pre-impoundment era. The existing upstream flow management programs for flood control and power production would continue, including the 427 KAF flow augmentation. In addition, the river has and will continue to be influenced by a number of point and nonpoint source discharges that have developed over the last several decades.

4.3 Discussion of Potential Water Quality Impacts

4.3.1 Water Temperature

Water temperature and increases in dissolved gas saturation levels represent two of the principal water quality concerns related to hydropower dam operations. Impoundments tend to change the timing and rate of water heating and cooling such that the seasonal rise and decline of water temperatures may differ from the inherent natural riverine patterns. Previous studies indicate that peak temperatures occur later in the summer and the autumn cooling period becomes more prolonged due to the heat attenuation in the impoundments compared to the free-flowing river (BPA, 1995; EPA and NMFS, 1971). These changes affect aquatic species that have adapted to the natural seasonal temperature cycles, especially native fish. The Corps and other agencies have made considerable efforts and expenditures to mitigate existing periodic problems associated with elevated temperatures during critical flow conditions, primarily through flow augmentation.

Existing flow augmentation efforts, where selective deep-water outlets are available (i.e., Dworshak Dam), have been shown to cause some minor reductions in water temperatures downstream (Bennett et al., 1997; Karr et al., 1997; NFSC-NMFS, 1971). The temperature reduction effect produced by the Dworshak Dam flow releases appears to be most critical during low-flow years.

The effect of increased flow augmentation on water temperature also depends on the temperature of the source waters used for augmentation. The deep cooler waters released from Dworshak Dam definitely provide some benefit; however, this dam has limited additional storage capacity to provide more flow beyond the existing flow augmentation volumes. The upper and middle Snake River dams do not have selective withdrawal facilities to release the deep, cooler temperature waters. Water released from the upstream Hells Canyon Complex dams would likely reach ambient temperatures by the time it reaches the lower Snake River reach approximately 160 miles downstream.

4.3.1.1 Alternative A1: Existing System—Existing Conditions

This alternative represents a continuation of the current system operations as they have been implemented since the issuance of the 1995 Biological Opinion by NMFS, including flow augmentation up to 427 KAF (thousand acre-feet).

The previous SOR temperature modeling predicted that under existing conditions the number of days exceeding a temperature threshold of 17.2°C (63°F) in the Lower Granite forebay would range between 67 for a high-flow year and 82 days for a low-flow year. The predicted 5-year annual average was 78 days. The number of days with observed water temperatures above 17.2°C (63°F), during the recent sampling years of 1994, 1995 and 1997, was slightly higher than these predictions. In 1994, a very low-flow year, there were an estimated 110 to 115 days with water temperatures above the 17.2°C (63°F) threshold. In 1995 (a cool summer season) and 1997 (high-flow year), the number of days exceeding 17.2°C (63°F) ranged from approximately 80 to 90 days. The historical data, presented in Section 3.2, indicate that water temperatures above 20°C (68°F) also commonly occurred prior to impoundment conditions.

4.3.1.2 Alternative A2: Existing System—Maximize Transport

Because flow operations will remain the same as Alternative A1, Alternative A2 is not expected to produce any discernable changes in water temperatures relative to existing conditions, either in the short or long term.

4.3.1.3 Alternatives A2a, A2b, and A2c

Similar to Alternative A2, these alternatives are not expected to cause any major short- or long-term changes in water temperatures relative to existing conditions. The major fish passage improvements proposed under both alternatives are not likely to change water temperatures.

4.3.1.4 Alternative A6a

Increasing the flow augmentation volume by 1.0 MAF, in addition to the current 427 KAF augmentation, as proposed under Alternative A6a, could offset the cooling effects of Dworshak Reservoir flow release, especially during low-flow years. The previous SOR modeling results suggest that increasing the flow augmentation volumes, using flow from the upper Snake River reservoirs, could increase the number of days with elevated water temperatures by as much 15 days in a low-flow year but only by 1 day during average flow conditions. This predicted increase is presumably due to the increased flow released from the upper Snake River, which is inherently warm water and could potentially negate the temperature reduction effect caused by releases from the Dworshak Dam. Increasing the flow augmentation in low-flow years results in the largest net gain in the number of days with elevated temperatures because in low-flow years the cooler water from the Dworshak Dam generally has the greatest effect on lowering temperatures. However, on average, a shorter cool-down period should occur in the fall because of the increased flow volumes and a reduced hydraulic residence time in the reservoirs. Therefore, on average, expected temperature changes would be minor but seasonal patterns may alter, especially in low-flow years. These changes would occur in the short term and continue into the long term.

4.3.1.5 Alternative A6b

Alternative A6b would eliminate flow augmentation, including the 427 KAF. Only regulated runoff volumes that mirror natural runoff patterns would be passed through lower Snake Reservoirs. Temperatures under Alternative A6b would presumably result in more days with elevated water temperatures, since the releases from Dworshak Dam, which have a cooling effect in the Snake River, especially during low-flow years, would be eliminated. Water temperatures would fluctuate as a result of meteorological conditions, without the influences of artificial cooling from flow augmentation. Reservoirs would be warmer, particularly during low-flow years. Long-term changes would parallel short-term changes.

4.3.1.6 Alternative A3: Natural River Drawdown

Temperature differences between the existing conditions and the drawdown alternative (normative or free-flowing system) were evaluated in two ways. First, measured data from 1994, 1995, and 1997 were compared with measured data from 1956 through 1958 at both Central Ferry (river mile 83.2) and Sacajawea near RM zero. Although the study years represent the spectrum of dry through wet conditions and the period 1956 through 1958 represents more average conditions, the comparison clearly shows some distinct differences. The existing impounded system also tended to

warm more slowly in the spring and cool slower in the fall due the larger volume of water and larger heat capacity of the impoundments compared to the free-flowing system. As previously described by Bennett et al. (1997), maximum temperatures during the summer months of July through August are anticipated to be approximately 2 to 5°C (4 to 9°F) higher under the free-flowing or normative system, approaching 26 to 27°C (79 to 81°F).

WQRRS model simulations for the drawdown alternative were also compared to the measured data for periods of similar hydrometeorological conditions (Normandeau, 1999a). Measured temperatures in the existing system are similar in magnitude to predicted temperatures except that temperatures in the existing system lagged those predicted for the drawdown. The time lag increased as the year progressed and river flows decreased, apparently related to increased travel times and volumes. Differences between the drawdown alternative and existing system progressively increased downstream.

Lowering the four impoundments to natural river elevations would produce a dramatic change in the volume and the heat storage capacity of open water in the lower Snake River. With less open water area and shallower depths, water temperatures over the long term will likely warm up faster early in the season but also cool down faster in early fall. The previous SOR modeling indicates that there would only be four fewer days with temperatures above the 17.2°C (63°F) threshold as compared to the existing conditions. Recent model results predict a more dramatic cool-down under certain hydrometeorologic conditions (Normandeau 1999a). Figure 4-1 illustrates the predicted temperatures in the Lower Granite forebay (RM 110.5) under the proposed drawdown alternative in comparison to the observed temperatures for each of the three sampling years. Using the same meteorological and hydrological data recorded during the sampling period as model input, water temperatures under the normative or free-flowing river system were predicted to drop to 15°C (59°F) at the end of the summer season approximately 15 days earlier than that observed during 1994, a low-flow year. During a high-flow year, such as in 1997, the difference between the predicted date for water temperatures to drop to 15°C (59°F) and the observed date under existing conditions was closer to five days. Thus, the maximum temperature benefit of the proposed drawdown alternative would occur during low-flow years.

The WQRRS temperature modeling results also suggest that water temperatures during low-flow years in the lower Snake River could reach higher summer peaks under the normative river conditions than under the existing impounded river conditions. Under wet and average hydrometeorlogic conditions, peak summer temperatures are projected to be similar to those observed for the existing system. WQRRS modeling results for 1994, 1995, and 1997 are presented graphically in Figures 5.5-1 through 5.5-12 in Normandeau, 1999a.

The EPA modeling study (Yearsley 1999) concluded that the likelihood that both duration and magnitude with which water temperatures exceed the benchmark (20° C) in the Snake River is greater with the dams in place than with the dams removed. Constraining tributary temperatures to less than 16° C does not change this result. The initial conditions at Lewiston, Idaho, upstream of the lower Snake River dams are such that the annual duration with which water temperatures exceed the benchmark is 11 percent of the year, and the average magnitude of this exceedance is 1° C. A comparison of the predicted frequency with which water temperatures are predicted to exceed 20° C in the existing and normative system is presented in Figures 4-2 and 4-3, respectively. At each of the dams, the predicted frequency with which water temperatures are expected to exceed 20° C is

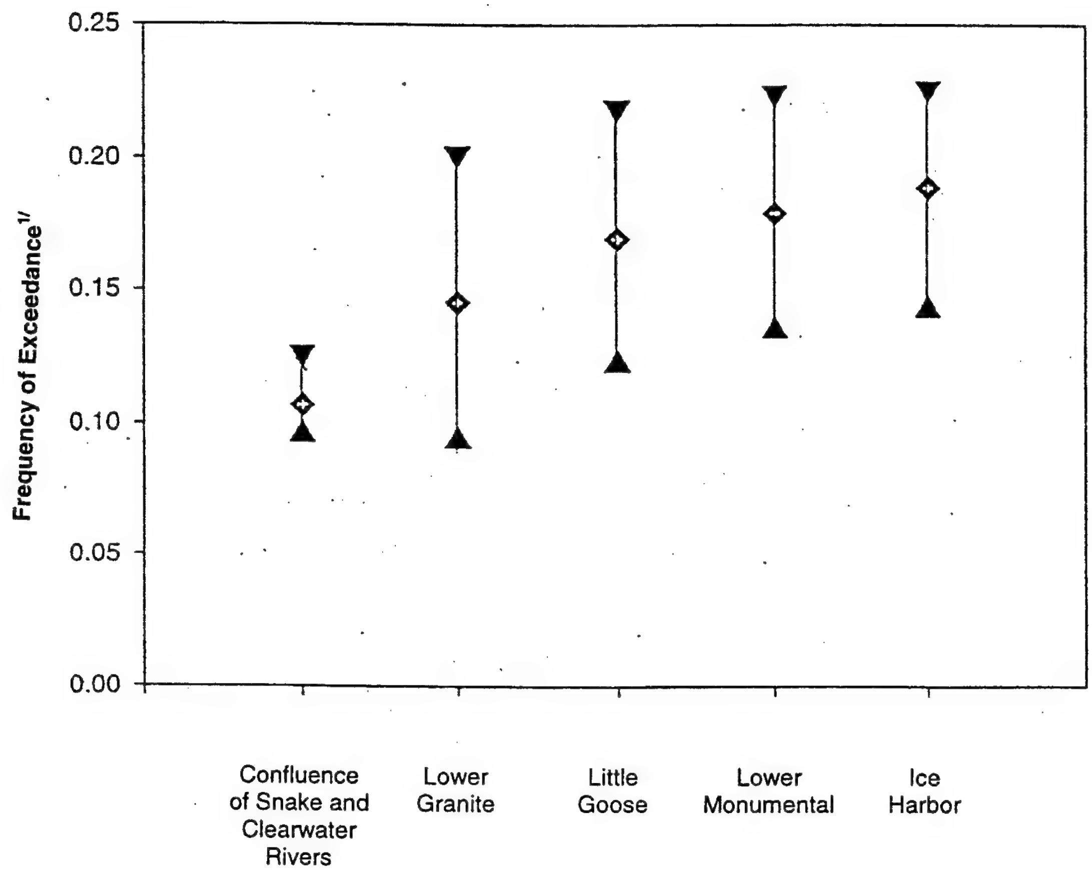
greater under the existing system than the normative system. The difference in predicted exceedance frequency between the existing and normative systems increases from upstream to downstream. With the dams in place, the Snake River increases the average annual duration of exceedance of 20° C in the Columbia River at the confluence from 4 percent of the year to 9 percent of the year (Figure 4-2). With the dams removed, the corresponding increase is less than 1 percent to nearly 3 percent (Figure 4-3). A comparison of the magnitude with which water temperatures exceed 20° C is presented in Figures 4-4 and 4-5. At each dam, the predicted magnitude of exceedance of 20° C is less than 0.25° C greater with the dams in place (less than 1° C increase above confluence, Figure 4-4) than in the normative system (less than 0.5° C increase above confluence, Figure 4-5). The difference in the predicted magnitude of exceedance increases from upstream to downstream.

The Pacific Northwest Laboratory study (Perkins and Richmond 1999) found that the primary difference between the current and natural river conditions scenarios is that the reservoirs decrease the water temperature variability. This is illustrated in Figures 4-6 and 4-7. Simulated temperature variability is similar at the beginning and end of the simulations (April and October), but variability is much greater in the normative scenario during the peak of the growing season (June through September). The reservoirs also create a thermal inertia effect that tends to keep water cooler later in the spring and warmer later into the fall compared to the natural river condition. This is similar to the results predicted by the WQRRS model (Normandeau 1999a). However, due to the uncertainties in the simulation model, the authors conclude that the results showed only small differences between the current and natural river temperature regimes.

As discussed in the preceding pages, three different models have been used to predict temperature in the lower Snake River: 1) WQRRS for unimpounded conditions, 2) the EPA model for impounded and unimpounded condition, and 3) MASS2 for impounded and unimpounded conditions. While the three models are all credible in their logic and fundamental temperature computation, it is worthy of note that they differ in the way they output their results. WQRRS predicts temperature for each day through the year and outputs that temperature. MASS2 calculates the temperature for each day, but then outputs the number of days the temperature exceeds several different levels. The EPA model calculates the temperature for each day and outputs the number of days the temperature exceeds the state water quality standard of 20°C.

As shown by the scroll case temperature data reported earlier, there is considerable variability in the maximum temperature reached each year and in the duration of excedance above the 68°F standard. Water temperatures in the reservoirs is a function primarily of the temperature of water entering from each of the annual flow volumes of Salmon River, the Clearwater River, and the Hells Canyon reach of the Snake River. Lower Granite Reservoir warms up first as the warm summer low flows replace cooler water from the spring, and it cools off first as cool water from the fall displaces the warmer summer water. Depending upon the source, inflow volume of water, and seasonal ambient air temperature, cool water releases from Dworshak Reservoir can reduce the maximum temperature by a few degrees and the duration of exceedance starting with Lower Granite Reservoir and diminishing as the water flows downstream through Ice Harbor Reservoir.

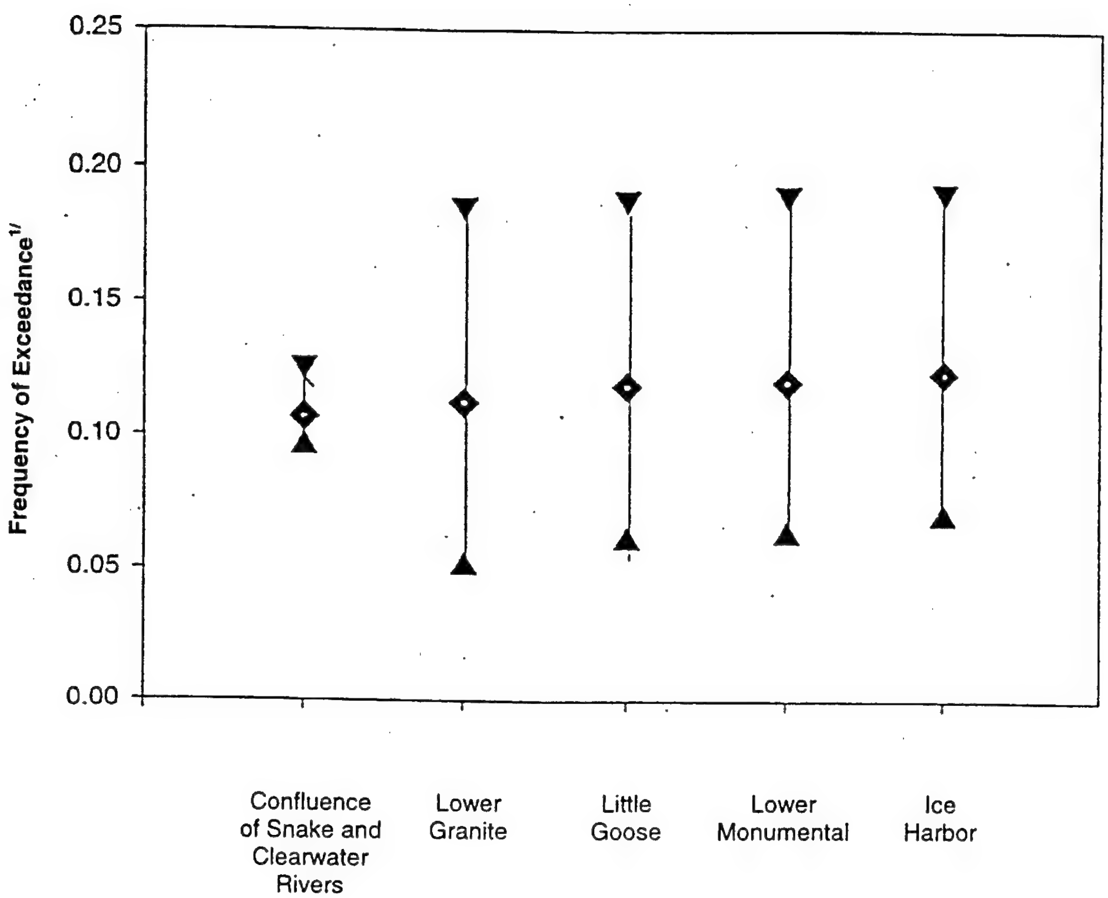
Short-term changes would be expected above and below dams as they are breached. Temperatures would equilibrate rapidly as the velocity of flow increases in the reservoir areas as they return to the natural river level. Upstream releases can still be used to moderate temperatures.



Source: Yearsley, 1999.

1/ Frequency of Exceedence is a percentage that equals the number of exceedences/number of observations

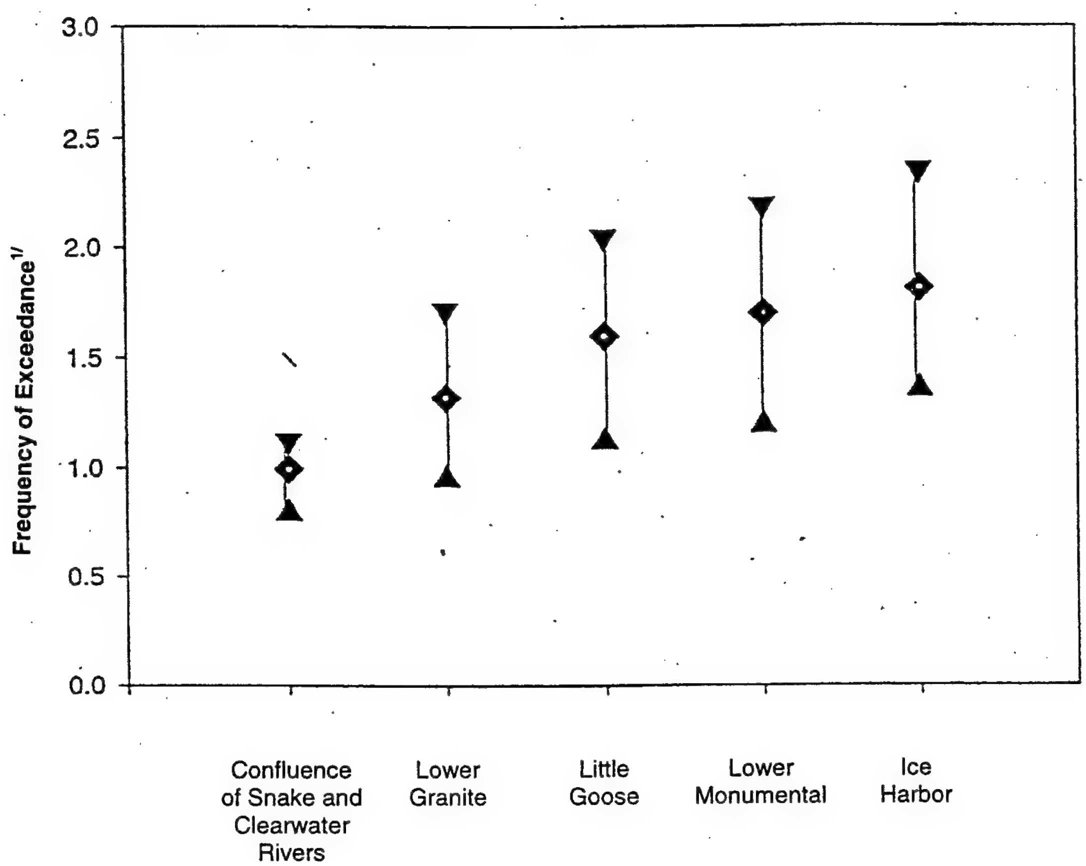
Figure 4-2. Estimated Frequency with which Water Temperatures Exceed 20 Degrees C in the Snake River with Dams in Place and Existing Management



Source: Yearsley, 1999.

1/ Frequency of Exceedence is a percentage that equals the number of exceedences/number of observations

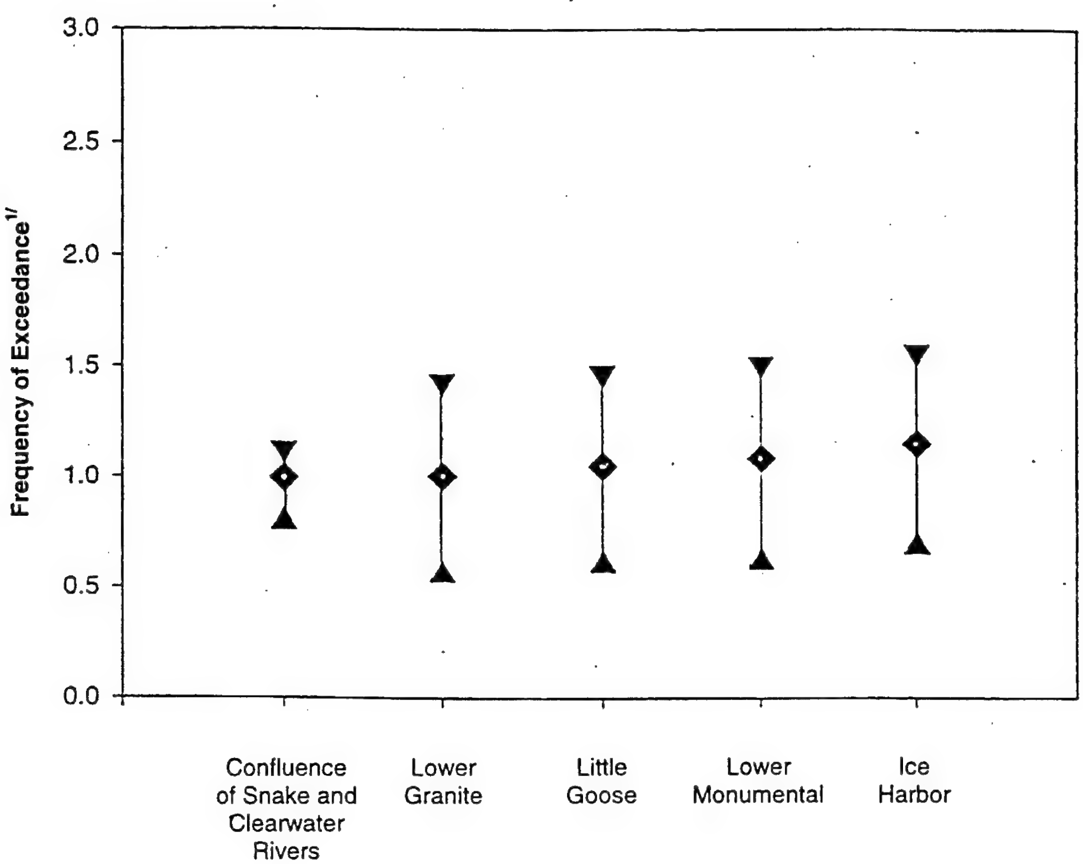
Figure 4-3. Estimated Frequency with which Water Temperatures Exceed 20 Degrees C in the Snake River with Dams Removed and Existing Management



Source: Yearsley, 1999.

1/ Frequency of Exceedence is a percentage that equals the number of exceedences/number of observations

Figure 4-4. Estimated Magnitude with which Water Temperatures Exceed 20 Degrees C in the Snake River with Dams in Place and Existing Management



Source: Yearsley, 1999.

1/ Frequency of Exceedence is a percentage that equals the number of exceedences/number of observations

Figure 4-5. Estimated Magnitude with which Water Temperatures Exceed 20 Degrees C in the Snake River with Dams Removed and Existing Management

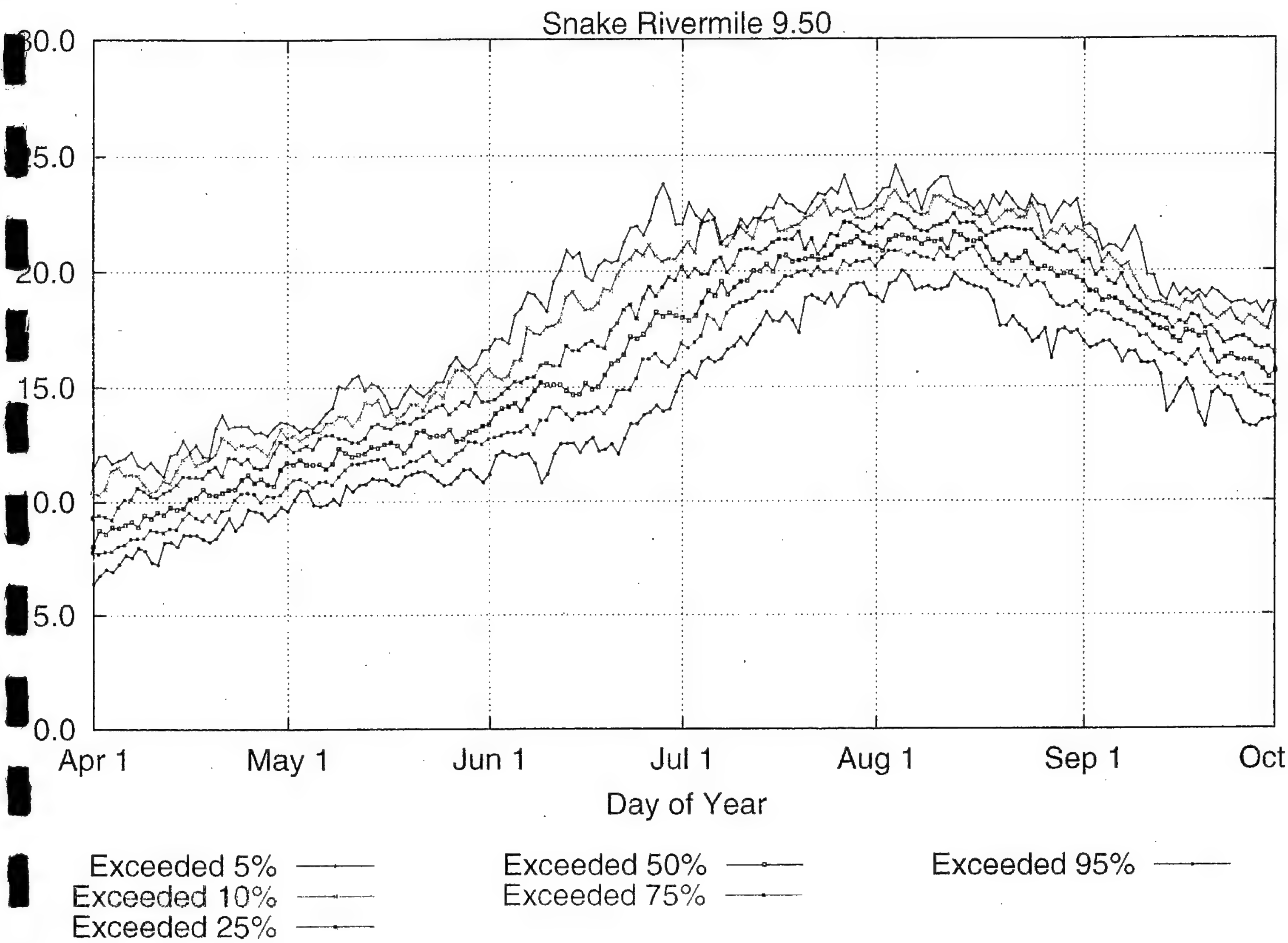


Figure 4-6. Summary of Mass 2 Simulated Temperature Variation at Snake River Mile 9.5 (near Ice Harbor Dam) during the Current Conditions Scenario

Source: Perkins and Richmond, 1999.

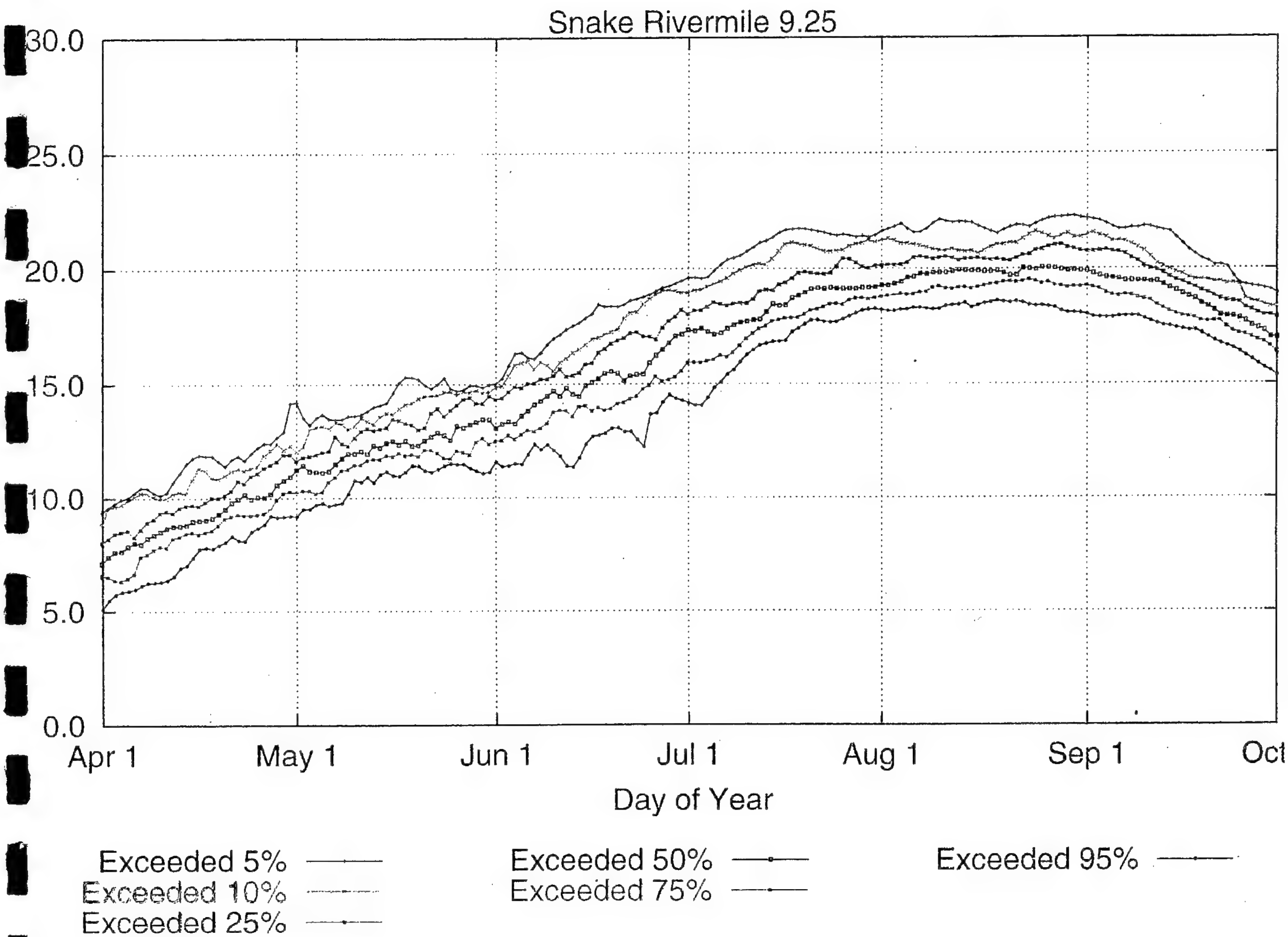


Figure 4-7. Summary of Mass 2 Simulated Temperature Variation at Snake River Mile 9.25 (near Ice Harbor Dam) during the Current Conditions Scenario

Source: Perkins and Richmond, 1999.

4.3.2 Total Dissolved Gas Saturation

A potential negative aspect to increased flow augmentation is that more water may need to be released in the dam spillways, which can increase dissolved gas saturation levels. Water that contains high total dissolved gases, hence high total gas pressure, can be harmful to fish. Total dissolved gas saturation is directly related to the amount and duration of spills. The Corps has instituted a program over the years to reduce gas entrainment in the tailwater by regulating spills based on measured total dissolved gas in the river above and below each dam. However, these measures have limited effectiveness if dissolved gas levels contributed from upstream are already elevated. Total dissolved gas saturation generally become progressively worse downstream as the waters pass through several spillways.

Alternative A6a, which would include increased flow augmentation, could also adversely affect TDG supersaturation due to increased flow releases through the spillways. The proposed natural river drawdown alternative, not surprisingly, would likely have the greatest positive effect on reducing the production and distribution of TDG supersaturation.

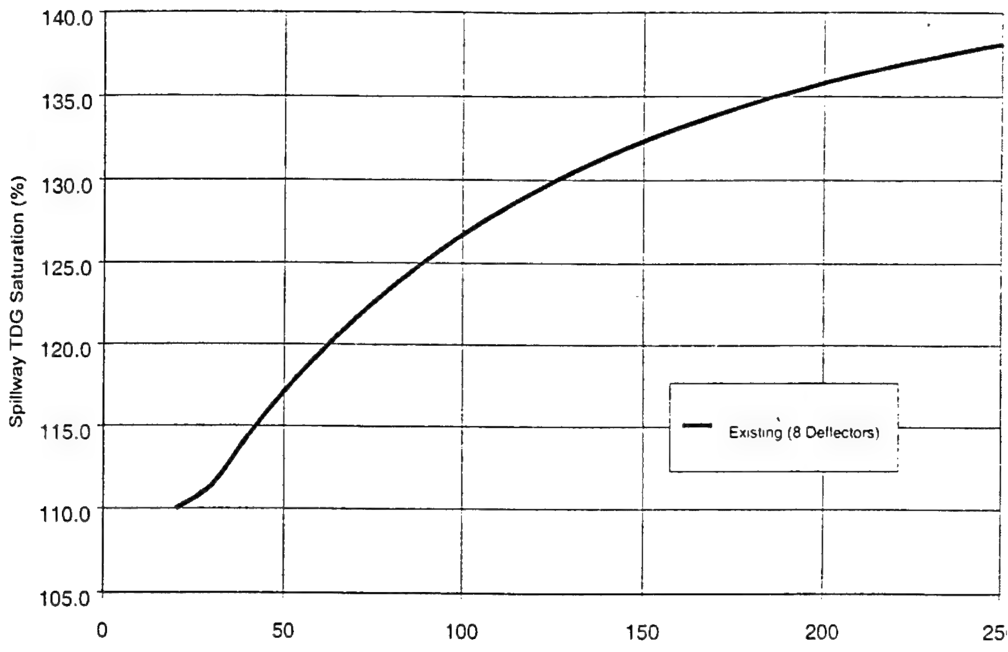
4.3.2.1 Alternative A1: Existing System—Existing Conditions

This alternative represents a continuation of the current system operations as they have been implemented since the issuance of the 1995 Biological Opinion by NMFS, including flow augmentation up to 427 KAF (thousand acre-feet). The addition of end bay deflectors at Lower Monumental and Little Goose is assumed for this alternative. Modified deflectors at Lower Monumental, Little Goose and Lower Granite are also assumed as part of this base case.

Spill to 120 percent TDG as defined in the 1995 and 1998 Biological Opinion would be executed. Forced spill would likely be similar to 1996-1998 operations. Spill caps could remain at current kcfs or be increased as TDG production is reduced due to spillway improvements. The increases in spill discharge to attain 120 percent TDG are estimated to be from 45 kcfs to 68 kcfs at Lower Granite, from 48 kcfs to 68 kcfs at Little Goose, and from 43 kcfs to 68 kcfs at Lower Monumental. The gas abatement improvements used with current voluntary spill discharges would result in TDG levels of 112 to 115 percent.

Total dissolved gas monitoring results from 1998 depict existing conditions in the tailwaters of the four dams on the lower Snake River (Corps, 1999). Transect data collected at the fixed monitored station (FMS) located 0.65 miles downstream of the Lower Granite spillway, indicate TDG can exceed 110 percent with spill discharges ranging from near zero to 30 kcfs and 120 percent TDG with spill flows of near 60 kcfs. Figure 4-8 illustrates the average TDG concentration generated by discharge from the existing spillway structure, assuming a uniform distribution of spill through all eight bays. It should be noted that special spill operations for the ongoing surface collection study significantly reduce the discharge through spillway bays 1 and 2. As a result TDG detected by the fixed monitoring station below Lower Granite may detect higher concentrations than that expected from a uniform spill distribution.

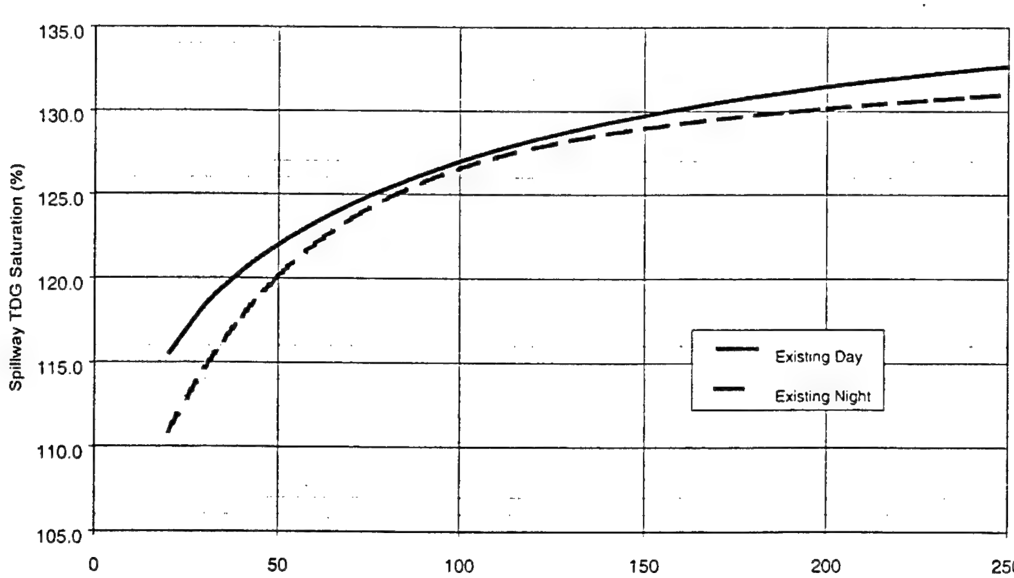
TDG data collected at the FMS located 0.85 mile downstream of the Little Goose spillway indicate TDG can exceed 110 percent with spill releases from near zero to 20 kcfs. When spilling uniformly through the six deflected bays, spill volumes of 45 to 50 kcfs will generate near 120 percent TDG.



Source: Corps, 1999.

Figure 4-8. Lower Granite Dam 1998 Total Dissolved Gas and Total Spillway Flow

The adult fish passage spill pattern requires in excess of 25 percent of the total spill volume through the two outside non-deflected spillway bays, allowing TDG to exceed 120 percent with as little as 25 kcfs. Figure 4-9 compares the average TDG concentration generated by daytime spill releases to the average concentration generated by nighttime releases. During the daylight hours the spill is distributed across the spillway according to the adult fish passage spill pattern. At night spill flows are released uniformly through the six deflected spillway bays.



Source: Corps, 1999.

Figure 4-9. 1998 Little Goose Dam Total Dissolved Gas and Total Spillway Flow (day-vs-night)

TDG data collected at the FMS located approximately 0.83 mile downstream of the Lower Monumental spillway indicate TDG can exceed 110 percent with spill releases from near zero to 16 kcfs. When spilling uniformly through the six deflected spillway bays spill volumes of 40 kcfs can be reached before exceeding 120 percent TDG. The daytime or adult fish passage spill pattern requires in excess of 25 percent of the total spill volume through the two outside non-deflected spillway bays, allowing TDG to exceed 120 percent with as little as 20 kcfs. Figure 4-10 was developed from near-field test results of the Lower Monumental spillway. This figure compares the TDG concentration generated by daytime and nighttime spillway releases.

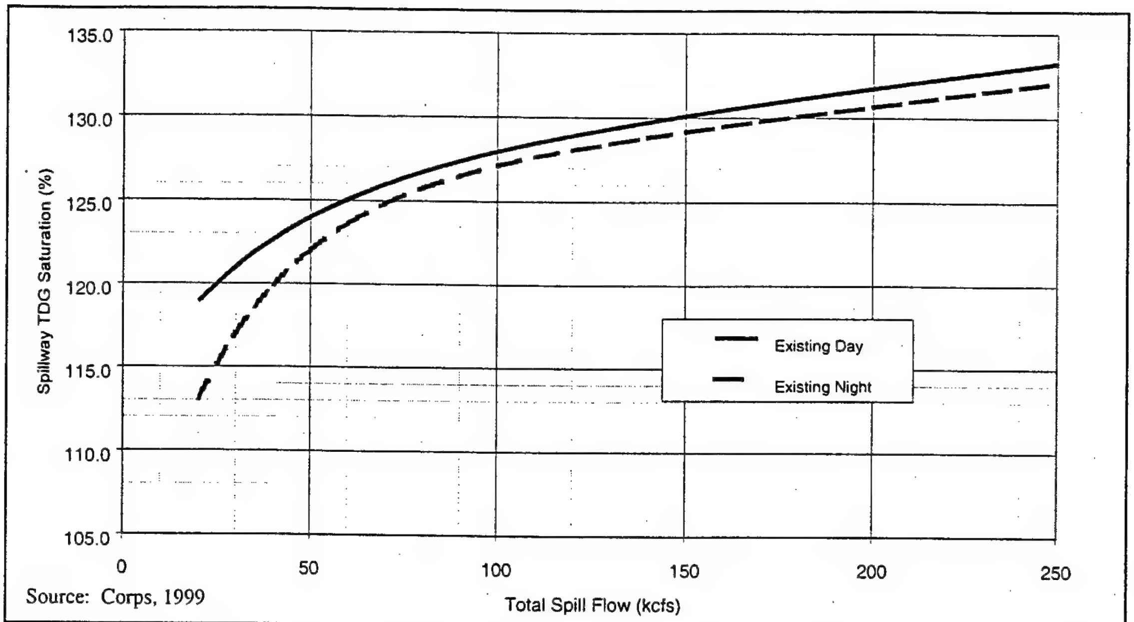


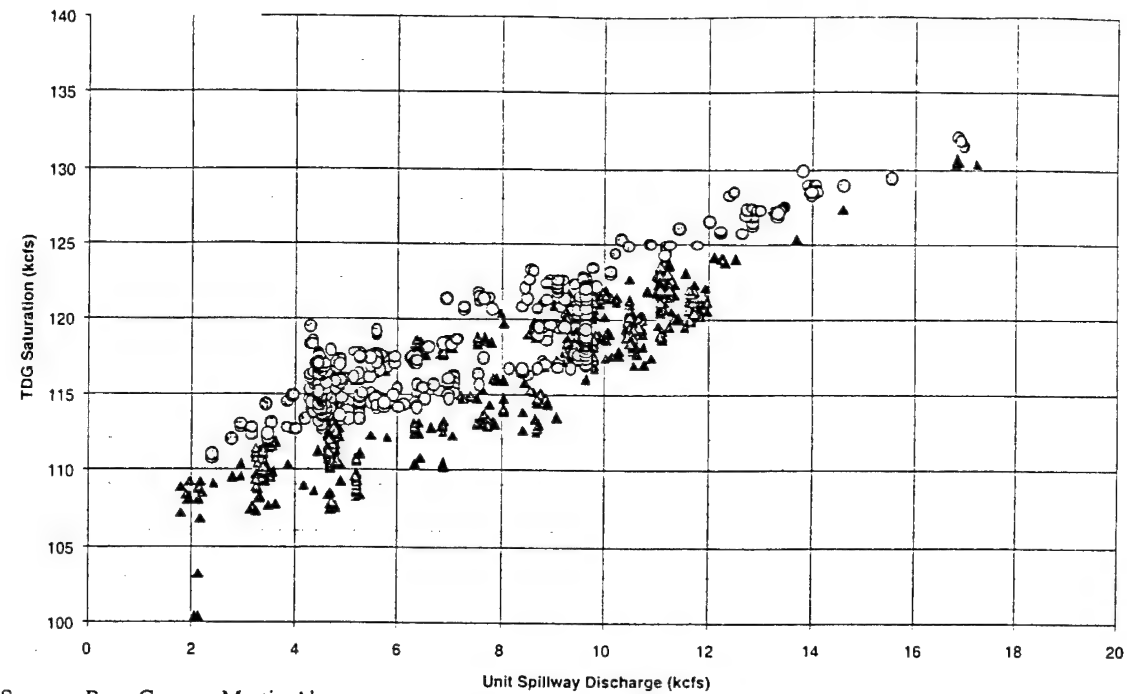
Figure 4-10. Lower Monumental Dam 1998 Total Dissolved Gas and Total Spill Flow (day-vs-night)

TDG data is collected at the FMS located approximately 3.6 miles downstream of the Ice Harbor spillway. The data indicates TDG of 110 percent can be exceeded with spill releases from near zero to 20 kcfs. Spill volumes have reached as high as 90 kcfs before exceeding 120 percent TDG. With construction of the two new deflectors in spillway bays 1 and 10, the 120 percent TDG may be expected to range from 90 to 100 kcfs. Figure 4-11 compares the existing 8-deflector performance to the expected 10-deflector performance and is the same actual data as in Figure 3-22. These plots have been generated from TDG measurements at the FMS below Ice Harbor.

Figure 4-12 illustrates 1998 spill season total discharge, spill discharge and resulting downstream TDG at Ice Harbor. The TDG response closely tracked spill discharge, even when averaged over six hours. Plots for the TDG stations in the rest of the Lower Snake River Dam tailwaters display similar characteristics.

4.3.2.2 Alternative A2: Existing System—Maximize Transport

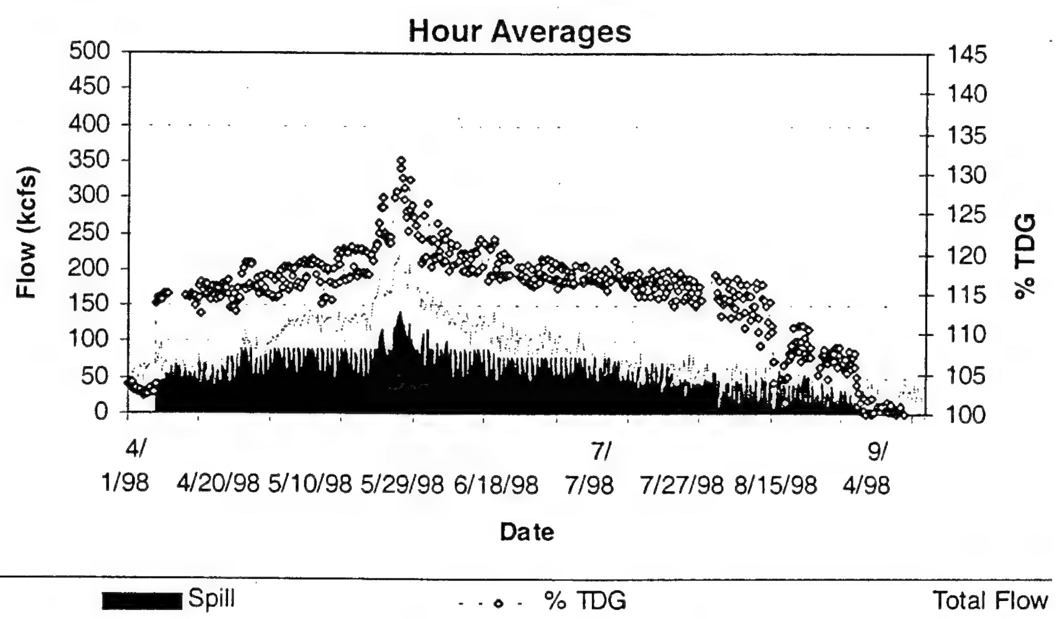
The addition of end bay deflectors at Lower Monumental and Little Goose is assumed for this alternative. Voluntary spill only remains for non-collected smolts at Ice Harbor under this alternative and the voluntary spill discharge cap of only 110 percent of TDG would be expected.



Source: Pers. Comm., Martin Ahmann, Hydraulic Engineer, Corps, Walla Walla District

Note: 8 of 10 deflectors installed in 1998, 10 of 10 installed in 1999.

Figure 4-11. Total Dissolved Gas Production Below Ice Harbor Dam, 1998-1999



Source: Corps, 1999

Figure 4-12. Ice Harbor 1998 Total Flow, Spill and Percent TDG at Downstream Fixed Monitoring Station (IDSW)-6

Forced spill would likely be similar to 1996-1998 operations. Supersaturation of TDG during involuntary spill conditions could still exceed 130-140 percent in tailwaters for several weeks system-wide. Production of TDG supersaturation at Lower Monumental and Little Goose would be reduced somewhat due to additional end bay deflectors. Because voluntary spill is eliminated at these facilities, increases in spill caps are not pertinent.

4.3.2.3 Alternatives A2a, A2b, and A2c

End bay deflectors at Lower Monumental and Little Goose would be added for these alternatives. The major fish passage improvements proposed under these alternatives would result in a small spill discharge resulting from dewatering of the Surface Bypass Collector over a spillway bay. This, however, would only lead to small increases in TDG loading to the system. A proportional increase in this source would occur as river flows decrease and TDG levels would have to be limited to 110 percent. For alternative A2a, voluntary spill only remains for non-collected smolts at Ice Harbor, and adherence to the voluntary spill discharge cap of only 110 percent of TDG would be expected. Forced spill would likely be similar to 1996-1998 operations. Supersaturation of TDG during involuntary spill conditions could still exceed 130-140 percent in tailwaters for several weeks system-wide. Production of TDG supersaturation at Lower Monumental and Little Goose would be reduced somewhat due to additional end bay deflectors. Because voluntary spill is eliminated, increases in spill caps are not pertinent.

4.3.2.4 Alternative A6a

Increasing the flow augmentation volume by 1.0 MAF, in addition to the current 427 KAF augmentation, as proposed under Alternative A6a could lead to increased involuntary spill. The addition of end bay deflectors at Lower Monumental and Little Goose is assumed for this alternative. Modified deflectors at Lower Monumental, Little Goose, and Lower Granite are also assumed as part of this alternative.

Spill to 120 percent TDG as defined in the 1995 and 1998 Biological Opinion would be executed. Forced spill would likely be similar to 1996-1998 operations. Spill caps could remain at current volumes or be increased as TDG production is reduced due to spillway improvements. The increases in spill discharge to attain 120 percent TDG are estimated to be from 45 kcfs to 68 kcfs at Lower Granite, from 48 kcfs to 68 kcfs at Little Goose, and from 43 kcfs to 68 kcfs at Lower Monumental. The gas abatement improvements used with current voluntary spill discharges would result in TDG levels of 112-115 percent.

The major fish passage improvements proposed under this alternative would result in a small spill discharge resulting from dewatering of the Surface Bypass Collector over a spillway bay. This, however, would only lead to very small increases in TDG loading to the system especially during the fish spill season. A proportional increase in this source would occur as river flows decrease and the fish spill season ends. After the fish spill season TDG would be limited to 110 percent for river certain flows.

The frequency and duration of (involuntary) spill at or above spill caps could increase with increased augmentation, resulting in higher total dissolved gas supersaturation and longer periods with TDG above the standard. This should be limited, however, because flow augmentation storage would likely be reserved for periods when river flows do not exceed powerhouse capacities.

4.3.2.5 Alternative A6b

Alternative A6b would eliminate flow augmentation, including the 427 KAF. Only regulated runoff volumes that mirror natural runoff patterns would be passed through lower Snake Reservoirs. The addition of end bay deflectors at Lower Monumental and Little Goose is assumed for this alternative. Modified deflectors at Lower Monumental, Little Goose, and Lower Granite are also assumed as part of this alternative.

Spill to 120 percent TDG as defined in the 1995 and 1998 Biological Opinion would be executed. Forced spill would likely be similar to 1996-1998 operations. Spill caps could remain at current volumes or be increased as TDG production is reduced due to spillway improvements. The increases in spill discharge to attain 120 percent TDG are estimated to be from 45 kcfs to 68 kcfs at Lower Granite, from 48 kcfs to 68 kcfs at Little Goose, and from 43 kcfs to 68 kcfs at Lower Monumental. The gas abatement improvements used with current voluntary spill discharges would result in TDG levels of 112-115 percent.

The major fish passage improvements proposed under this alternative would result in a small spill discharge resulting from dewatering of the Surface Bypass Collector over a spillway bay. This, however, would only lead to small increases in TDG loading to the system. A proportional increase in this source would occur as river flows decrease and the fish spill season ends. After the fish spill season TDG supersaturation would be limited to 110 percent for certain rivers.

The frequency and duration of spill at or above spill caps could decrease, resulting in lower TDG and shorter periods with TDG above the standard. This should be limited, however, because flow augmentation operations would be reserved for periods when river flows do not exceed powerhouse capacities.

4.3.2.6 Alternative A3: Natural River Drawdown

Under this alternative, there would be essentially no more hydraulic head at the four lower Snake River dams and therefore no spill. However, due to formation of plunge pools during resetting of quasi-equilibrated fluvial geomorphology of channel and water temperature dynamics, geographically localized TDG above 110 percent is possible infrequently and for short durations. Maximum salmonid production requires active management of increasing flow magnitude and frequency according to historical shaping. This could increase frequency of increased spill from Hells Canyon and Dworshak Dams in large pulses to lower Columbia River dams, which could likely remain at spill caps regulated by 120 percent TDG waivers.

4.3.3 Sediment Movement and Related Downstream Impacts

Changes in sediment movement are affected by flow rate and water depth. Flow rate and water depth in turn affect erosion and downstream sediment movement and increase suspended sediments. All the above process impact water quality and primary productivity.

4.3.3.1 Alternative A1: Existing System—Existing Condition

Under existing conditions, the total annual sediment influx to the lower Snake River system has been estimated to be around 2.3 million cubic meters (3 million cubic yards). Much of this sediment is contributed from the middle and upper reaches of the Snake River. However, a significant portion may be contributed from several of the smaller tributaries, especially the Palouse River. Although

flow contributions from the Palouse River are relatively minor and generally account for less than 1 percent of the total flow, peak suspended sediment concentrations have been reported to be more than 10 times greater than that measured in the Snake River. Based on the 1997 data, suspended sediment concentrations throughout the lower Snake River were generally below 25 mg/L, with peak concentrations ranging between 50 and 75 mg/L. The peak concentrations in the Palouse River were well above 1,000 mg/L and averaged around 200 mg/L for the sampling season.

As mentioned earlier, since the construction of the four dams, turbidity levels and suspended concentrations in the lower Snake River have generally been viewed as being considerably reduced from pre-impoundment conditions due to the slower flow velocities in each of the impoundments, allowing for greater settling. In general, the net effect was more likely reflected in a reduction in suspended sediment concentrations rather than the turbidity levels. Turbidity data collected from 1954 to 1957, prior to dam construction, indicate that turbidity levels typically ranged from 10 to 20 NTUs in the lower Snake River and higher during peak flow periods (BPA, 1995). During the 1997 sampling season, except for some occasional peak levels of 15 to 20 NTUs during the spring freshet, turbidity levels throughout the lower Snake River were typically below 10 NTUs. Because monthly flow conditions during 1997 generally were well above normal, the observed suspended sediment and turbidity levels would also be expected to be above normal. In general, the existing turbidity levels and suspended sediment concentrations are considered to be below levels that may be harmful for fisheries and other aquatic life. However, periods of elevated turbidity levels above 10 NTUs, typically during the spring freshet, can temporarily have an adverse effect or require additional treatment for downstream potable and irrigation water supply users.

4.3.3.2 Alternative A2: Existing System—Maximum Transport

Flow operations under the maximum transport alternative would be the same as Alternative A1, and, therefore, no significant short-term or long-term changes in sediment erosion and movement would be expected.

4.3.3.3 Alternatives A2a, A2b, A2c, A6a and A6b: Major System Improvements

Similar to Alternative A2, significant changes in sediment erosion and movement would not be expected with any of the four alternatives included in the major system improvements pathway. Alternatives A2a, A2b, and A2c, which have no changes in the flow augmentation regime compared to the existing conditions, are not expected to alter sediment transport or the potential for erosion. Alternative A6a would potentially add an additional 1.0 MAF of flow from the upper Snake River from April through August. In addition, spills would be maximized. The amount of flow volume compared to existing would triple. Velocities, especially in the main channel, would increase both in the short term and long term, potentially increasing suspended solids and erosion. However, this additional flow is not expected to produce flow volumes any greater than those that occur annually during the spring freshet. Furthermore, the main channel is predominantly coarse-grained sediments, which would have a low potential for erosion. As a result, short term or long term increases in sediment scour would not be expected. The increase in flow volume will reduce the concentration of suspended sediments, nutrients, and dissolved oxygen. Alternative 6b, with zero flow augmentation, is not expected to result in a substantial change in erosion potential or sediment movement.

4.3.3.4 Alternative A3: Natural River Drawdown

To understand and explain differences in the water quality and biological production of the existing conditions and drawdown alternative (normative system), some understanding of the difference in physical characteristics expected between the two is necessary. As part of the Columbia River Salmon Mitigation Analysis System Configuration Study Phase (BPA, 1995), the Corps developed time of travel curves as a function of river flow for the study reach for various alternatives using HEC-2 model simulations. A comparison of the curves shows that the time of travel for the drawdown alternative is about one order of magnitude less than for the existing conditions. At a typical summer low flow of about 25 kcfs, travel time from the Clearwater River to Columbia River for the existing conditions is about 35 days compared to about 2.5 days for the drawdown alternative. At a typical May-June flow of 120 kcfs, travel time would be on the order of 1 day for the drawdown alternative and 7 days for the existing conditions. Therefore, breaching the dams would be expected to have very rapid flushing compared to the existing conditions.

Water depths and available habitat also would be expected to vary significantly between the existing conditions and the dam breaching alternative. Flow depths currently remain relatively constant throughout the year and range from about 20 feet in the tailwater areas to over 100 feet at the dams. In contrast, flow depths will vary seasonally with flow with the drawdown alternative. During a typical spring runoff period (120 kcfs), average flow depth over a cross section will be on the order of 25 feet compared to 15 feet during a typical summer flow condition. Differences in surface area or average width will not be as drastic. The total surface area for the existing system is currently approximately 33,236 acres compared to 19,464 acres expected for the drawdown alternative. Reduced volume will affect concentrations of water quality.

Over time, the bottom substrate will likely change following drawdown. The existing reservoirs contain embedded fine sediments that have accumulated over a 40-year period. It is anticipated that extremely high river flows (>200,000 cfs) would be necessary to resuspend fine sediments and remove interstitial materials. A geomorphological study that evaluates the river flows and substrate changes following drawdown (Hanrahan et al., 1999) indicates that with sufficient flows over time, the substrate will consist primarily of bedrock and boulders in fast-moving sections and cobble in slow-moving sections.

One of the primary water quality concerns associated with this alternative relates to the potential for considerable increases in suspended sediment concentrations and turbidity levels as the accumulated sediment behind these dams becomes resuspended and moves downstream. The potential increases may reach levels during the initial drawdown period that could adversely affect aquatic biota and other beneficial uses. The increased turbidity can adversely affect both primary food production (i.e., phytoplankton and attached benthic algae growth) and fish feeding efficiency. In addition, depending on the magnitude of the TSS concentrations, impairments to other biological functions such as respiration (i.e., gill clogging) and reproduction are possible.

Recent sediment volume estimates developed by the Hydrology Branch of the Corps Walla Walla District indicate that approximately 76 to 155 million cubic meters (100 to 150 million cubic yards) of sediment has accumulated behind the four lower Snake River dams. In addition, approximately 50 percent of this previously deposited sediment is expected to erode and move downstream within the first few years following dam breaching, particularly during peak flow periods (Corps, 1998a). This translates to about 50 to 75 million cubic yards of material that could move downstream. Most

of this eroded material is expected to settle out downstream in the McNary Reservoir. The McNary Reservoir is generally considered to have comparatively lower-flow velocities than those in the lower Snake River impoundments, mainly because it is nearly twice the size of the largest reservoir in the lower Snake River. More-recent analyses indicate that sediment is expected to accumulate mainly on the eastern shore of McNary reservoir between the Snake River Confluence and Wallula Gap. Smaller areas of deposition are anticipated on the opposite shoreline, on the western shore immediately downstream of Wallula Gap, and just upstream of McNary Dam (Appendix F, Hydrology – Hydraulics and Sedimentation, Corps, 1999).

The previous SOR modeling efforts utilized the HEC-5Q model to predict suspended concentrations under the proposed drawdown scenario relative to existing conditions. The modeling results provided an estimate of the amount of time (expressed as a percentage of time on an annual basis) that sediment concentrations are likely to exceed 25 mg/L (about 18 NTUs). The 25 mg/L threshold was selected based on protection of fish (BPA, 1995). It compares reasonably well with the average TSS level observed in the Snake River reach based on the 1997 data. It is, therefore, assumed that the 25 mg/L threshold reflects background conditions.

Predictions of post-drawdown water quality focus on total suspended solids (TSS), which does not have associated water quality standards, rather than turbidity, which is used in state water quality classification (Table 3-1). The predicted TSS levels indicate that turbidity standards would also be violated at an unknown frequency. TSS would exceed the protective level of 25 mg/L threshold approximately 36 percent of the time during the first year following breaching of all four dams. This frequency would be reduced under the two-dam, 2-year scenario that is presently proposed. TSS concentrations would adversely affect primary producers, benthic habitat, and fish.

The 25 mg/L TSS threshold has potential sublethal effects for adult salmonids and lethal effects for juveniles (Newcombe and Jensen, 1996). Adult salmon had reduced feeding activity after four hours' exposure to 25 mg/L TSS (Phillips, 1970). However, Newcombe and Jensen (1996), in their review article of TSS effects on fish, saw no evidence of ill effects of 25 mg/L TSS on adult salmonids. They theorized that TSS at 20 mg/L would show sublethal effects at four months' exposure. Arctic grayling salmon showed an avoidance response after 24 hours' exposure at 20 mg/L (Birtwell et al., 1984). Larvae had a 5.7 percent mortality at 24 hours' of exposure at 25 mg/L (Newcombe and Jensen, 1996). Juvenile coho salmon showed decreased feeding rates at one-hour exposure at 25 mg/L (Noggle, 1978), and increased physiological stress at 12 hours' exposure at 53.5 mg/L. Newcombe and Jensen (1996) predicted that a two-week exposure of juvenile salmonids to 20 mg/L TSS would cause severe effects.

Under the natural drawdown alternative, with a similar proposed breaching of four dams, sediment concentrations, during the first year following breaching, were predicted to exceed the 25 mg/L threshold approximately 36 percent of the time or 131 days per year. The average exceedance period for the next 15 years was estimated to be 25 percent of the time or roughly 91 days. This compares to no exceedances of the 25 mg/L threshold predicted under the existing conditions. Although these predictions do not indicate the magnitude to which sediment concentrations may occur, from a relative comparison, the predicted increase in the number of days where suspended solid concentrations exceed 25 mg/L under natural drawdown conditions represents a substantial increase over existing conditions.

During the 1992 drawdown test conducted in the Lower Granite Reservoir, suspended sediment concentrations were observed to be as high as 2,000 mg/L (Corps, 1992a). During this test, water levels were only lowered by 10 meters (33 feet), and peak flow conditions and rainfall events were not encountered. In addition, during the 1992 drawdown test, substantial "mud flat" areas were observed along the shoreline areas. Even more extensive mud flat areas would be expected under the proposed conditions, which will be vulnerable to erosion and downstream movement, especially during subsequent peak flow periods. TSS concentrations are expected to be much higher during the proposed drawdown conditions (up to 9,000 mg/L at Ice Harbor Dam (Normandeau, 1999b), until the new channel bed and banks stabilize and equilibrate with the flow regime. At these concentrations, TSS has caused increased mortality of juvenile chinook, egg, fry, smolt, and under-yearling coho, and juvenile and under-yearling sockeye (Newcombe and Jensen, 1996).

The deposition of eroded sediment downstream represents another principal concern mostly from a physical habitat standpoint rather than a water quality concern. Because the flow velocities in Lake Wallula (McNary Reservoir) are considered to be lower than that observed in the lower Snake River reservoirs, most of this eroded sediment is expected to drop out in the upper portions of the McNary Reservoir near the mouth of the Snake River. The coarsest sediment will settle out first in the vicinity of the Ice Harbor Dam and the finer-grained sediment will progressively settle out farther downstream. The very fine sediments that do not deposit in Lake Wallula will continue to be conveyed downstream of McNary Dam with their ultimate destination likely being the Columbia River Estuary or the Pacific Ocean.

It is difficult to estimate the volumes and the locations in which the various sized particles that make up the accumulated sediment will be re-distributed downstream. The previous SOR modeling indicated that most of this sediment would be re-deposited in the upper end of the McNary Reservoir between RM 320 and 325 on the Columbia River and RM 0 and 10 on the lower Snake River. The maximum accumulation rate was estimated to be approximately 230 kg/m^2 (BPA, 1995).

As a means of developing a rough estimate of the average depth of newly deposited sediment downstream, 1 million cubic yards of sediment will cover an area equal to 1 square mile to a depth of 1 foot. The McNary Reservoir is a large water body with an estimated surface area of approximately 30 square miles compared to an estimated surface area of nearly 17 square miles for the Little Goose Reservoir, which is the largest of the four lower Snake River reservoirs. Given that 50 to 75 million cubic yards are expected to move downstream, the average depth of new sediment deposited in the McNary Reservoir could range between 0.5 to 0.75 meters (1.7 and 2.5 feet), assuming the sediment is equally redistributed throughout the entire impoundment. Realistically, the eroded sediment will not be equally distributed throughout the water body and will most likely to be contained and deposited within the main river channel within the impoundment. Assuming one-third of the entire reservoir area represents the primary deposition zone, the depth of new sediment could be as much as 1.3 meters (4.2 feet). This potential depth of material is not likely to present navigation problems since most of the McNary Reservoir is greater than 20 meters deep. However, this could present problems with existing water withdrawal intakes, including those used for drinking water supply. In addition, redeposited sediment would likely cover large areas of benthic habitat, which, in turn, could cause a major short-term disruption in the primary productivity and food supply for benthivores and other bottom feeders.

The system would undergo a short-term transition period during drawdown. Under the two-year two-dam scenario, Lower Granite and Little Goose Dams would be removed. Sediments would be scoured from these two reservoirs and redeposited in Lower Monumental Reservoir. TSSs would increase in the river between these two points. A similar situation would occur as Lower Monumental and Ice Harbor reservoirs are breached, and sediments are transported to McNary Reservoir. The peak suspended sediment is estimated to be highest at Ice Harbor (9,000 mg/L), followed by Lower Monumental (7,000 mg/L), Little Goose (6,000 mg/L) and Lower Granite (3,600 mg/L; Normandeau, 1999b).

The release of other water quality constituents currently attached to bottom sediments represents another major concern to downstream beneficial uses. The previous SOR study modeled the potential for increases in DDT, lead and ammonia in the water column. Moderate increases in the percentage of time exceeding certain concentration thresholds were predicted for the natural river drawdown scenario as compared to existing conditions.

The SOR results were updated with recent sediment and elutriate test results as well as revised sediment volume estimates (Normandeau, 1999b, Appendix B). The results of the analyses of sediment samples collected from the lower Snake River and their ambient pH elutriates were compared with state and federal guidelines for surface water and sediment quality to identify any CoCs. Two parameters exceeded their respective sediment quality criteria. Total DDT (using US Army Corps of Engineers 1998 Lower Columbia River Dredged Material Evaluation Handbook) and dioxin toxicity equivalence quantities (TEQ), based on N.Y. Department of Conservation (NYDEC) 1998 Technical Guidance for Screening Contaminated Sediments. Four metals and one organic compound exceeded applicable water quality criteria in the elutriate testing: arsenic (Oregon 1998 Water Quality Criteria [ODEQ]); copper (EPA National Recommended Water Quality Criteria); mercury and manganese (ODEQ); and ethyl parathion (ODEQ and Washington State Freshwater Sediment Quality Values [Ecology]). Of these, three CoCs were selected based on the level and frequency of occurrence and comparison to relevant background levels: dioxin TEQ (sediment), total DDT (sediment), and manganese (water).

Points of compliance, locations where CoCs exceed the relevant sediment or water quality criteria, were selected that reflect the likely beneficial use (and therefore potential impacts) in the areas where exceeded. The criteria reflect the protection of piscivorous wildlife (total DDT and dioxin TEQ), human health (DDT from bioaccumulation and manganese from drinking water and fish), invertebrate communities (total DDT in sediments), and agricultural uses (manganese in irrigation water).

Dioxin and DDT were only detected in sediment, so the potential areas of concern would include those areas where these organic compounds were detected and where they will be redeposited after the natural river drawdown alternative is implemented. Dioxin was only found in samples collected from Lower Granite Lake downstream from Clarkston-Lewiston, while total DDT was detected in the sediments behind each of the dams. Following the implementation of natural river drawdown alternative it is expected that the resuspended sediments will be deposited behind the McNary Dam.

Manganese was found to partition from the sediment and into water (elutriate) at concentrations which exceeded the State of Oregon surface water quality standard of 50 ppb. Thus, the quality of surface water and its suitability for use may be compromised. To evaluate the potential impact of the release of manganese on the lower Snake River water users, the number and type of users was

inventoried. Identified water users in the study area include at least 23 withdrawals on the lower Snake River for irrigation use, a pulp and paper mill located near Burbank, Washington and the Port of Hermiston, Oregon withdrawal on the Columbia River, which is used for public water supply. For the purposes of this investigation, five points of points of compliance for manganese were selected including: the Port of Hermiston municipal intake and the reaches 300 feet below each of the dams.

The potential impact of dioxin TEQ, total DDT and manganese was evaluated by revising the hydrologic simulations performed as part of the System Operation Review (BPA et al., 1995) for the Columbia River. The revisions to the SOR HEC-5Q simulations took into consideration the differences in the alternative evaluated, different partition coefficients, new estimates of sediment accumulation and different CoC concentration data. In the SOR simulations ammonia, DDT and lead were identified as the CoC. Based on the results of the analytical testing and their screening with applicable standards ammonia and lead were replaced by dioxin TEQ and manganese.

The results of the revisions to the SOR HEC-5Q model indicate that the peak suspended sediment concentration would 9,000 mg/l, or twice the original estimate. The estimated volume of sediment accumulation in the McNary Reservoir is 24.1 million cubic yards or 3.4 times greater than the original estimates. Although the concentration and volume of sediment is expected to be higher than originally estimated, the concentrations of total DDT and dioxin TEQ were not found to exceed their respective sediment quality criteria at any of the points of compliance.

The increase in suspended sediment concentrations and the partitioning of manganese from the sediment into the water column may result in the degradation of water quality below acceptable limits. The estimated range of manganese concentrations (394 ppm to 1328 ppm) exceeds both the limit of 50 ppb for the protection of human health (State of Oregon) and 200 ppb for agricultural use (United Nations) at below each of the four dams. Manganèse concentrations are expected to be within standards at the Port of Hermiston (Normandeau, 1999b).

Manganese is usually not considered a human or environmental health risk. EPA criteria are based upon its effects on the aesthetic properties of water for domestic use. The presence of manganese at concentrations higher than 150 μg/L imparts an undesirable taste and browns laundry (EPA 1976). Manganese is usually found in salts and other compounds, but is not found naturally as a metal. The concentration of manganese ions in nature is rarely higher than 1 mg/L, and most freshwater organisms tolerate concentrations between 1.5 to 1,000 mg/L (EPA 1976). Similar to other metals, the solubility of manganese is affected by pH and dissolved oxygen which tends to cause manganese to precipitate. AFS (1979) reported studies indicating that several freshwater fish species survived exposures to concentrations of manganese up to 2,700 mg/L. Permanganates, a family of manganese-containing compounds, is reported to have a 96-hour LD50 (lethal dose that results in 50 percent mortality in 96 hours of exposure) of 16 mg/L for young rainbow trout (AFS 1979). Manganese sulfate has also been cited as deleterious to rainbow trout eggs at concentrations of 0.37 to 4.0 mg/L, but had no effect on fry (AFS 1979). Overall, it appears that the presence of manganese at 3,680 μg/L from the elutriate screening test is not a direct concern to salmonids. However, it is indicative of one or more sources of manganese compounds entering the system and should be a concern relative to domestic water supplies.

Total DDT concentration is the sum of 4,4-DDT and its two metabolites 4,4-DDE and 4,4-DDD. Current Washington State criteria are 1.1 μg/L for instantaneous concentrations and .001 μg/L under

chronic (24-hour-average) conditions. LD50s for chinook salmon and coho salmon have been measured at 12 µg/L and 14 µg/L, respectively. DDT and its metabolites affect salmonids at both acute and sub-lethal levels (EPA 1980). Sub-lethal effects to salmonids (not necessarily Pacific salmon) include inhibition of Na^+-K^+ ATPase (an enzyme important to immune response), reduced light discrimination, altered temperature selection, changes in avoidance behavior, and lateral line hypersensitivity. DDT can bioaccumulate in tissues, consequently tissue burdens may increase for larger predatory fish, birds, and mammals that utilize forage species exposed to DDT. Model results suggest that aquatic DDT levels could nearly match the chronic criteria level at Lower Granite Dam during Year 1, but should be far below the acute toxic levels. Consequently, the results suggest there is a potential for sub-lethal effects during the first year of drawdown at Lower Granite Dam.

Dioxin is highly toxic to a variety of species (EPA 1998). In addition, it is highly stable, resistant to leaching and biodegradation, and only slightly soluble in water. As a result of its relative insolubility in water, dioxins affect salmonids primarily through bioaccumulation from forage species and through direct exposure to sediments to which dioxin is bound. Dioxin affects the immune response in organisms and can cause cancer and liver damage (EPA 1998). In addition, Walker et al. (1991) demonstrated high sensitivity of salmonids during the egg and alevin life stages. They reported LD50 levels of 65 parts per trillion (ppt) for lake trout eggs, which compared to LD50 levels of 300 ppt for rainbow trout alevins. Lake fry trout experienced fluid accumulations in their yolk sacs and subcutaneous hemorrhages. Existing sediment concentrations (1.0 ppt maximum in the four samples collected) are well below these levels. Currently there are no freshwater dissolved dioxin (2,3,7,8-TCDD congener) criteria recommended by EPA, but a criterion of 1.3×10^{-8} µg/L is recommended for human consumption of water and organisms (Federal Register 63, No. 237, December 10, 1998). However, NYDEC recommends a toxicity equivalence quotient (TEQ) for the 19 dioxin congeners of 0.0002 mg/kg (NYDEC 1998). Peak model predictions for dioxin levels are not expected to exceed the NYDEC criteria under any of the modeled scenarios.

4.3.4 Primary Productivity

4.3.4.1 Alternative A1: Existing System—Existing Conditions

Primary productivity throughout the lower Snake system can be categorized as mesotrophic to eutrophic based on both chlorophyll *a* concentrations and phytoplankton densities. Seasonal peaks in chlorophyll *a* and phytoplankton density occurred in June, due to diatoms, and September. Spatially, algal densities were highest upstream and declined downstream. Phytoplankton was the primary source of primary productivity, peaking in June/July and again in autumn. The lower Snake had the highest densities. Diatoms predominated, and species composition did not vary between riverine and impounded areas. Low velocities, warm water, and large surface water areas produced favorable conditions to algal production. Phosphorus concentrations were sufficient to potentially cause eutrophic conditions.

4.3.4.2 Alternative A2: Existing System—Maximize Transport

Alternative A2 is similar to existing conditions, with the exception of the elimination of spills and maximization of transport. As factors affecting primary productivity such as temperature and velocity would not change with this alternative, primary productivity would also not be expected to change over the short-term or long-term time frames.

4.3.4.3 Alternatives A2a, 2b, 2c, 6a, and 6b: Major System Improvements

The system improvement Alternatives 2a, 2b, and 2c have no differences in spill or flow augmentation, so will not change the physico-chemical environment. Therefore, there should be no short or long-term changes in the type or level of primary productivity compared to existing conditions.

Alternative 6a, which has an additional 1.0 MAF of flow augmentation, could increase days with elevated temperatures, particularly during low flow conditions. Cool-down in fall would be more rapid, because of increased flow volumes and reduced hydraulic residence time. The changes in temperature are expected to be minor, but could cause short and long-term increases in primary productivity in spring and reductions in fall. The increase in volume will increase depth in the reservoir and likely decrease light penetration. These effects would be balanced with increased temperature.

Alternative 6b, which eliminates all flow augmentation, including the 427 KAF, would likely result in fewer days with elevated temperatures, but also warmer reservoirs during warm, low-flow years. No substantial short-term or long-term changes are expected in primary productivity compared to existing conditions.

4.3.4.4 Alternative 3: Natural River Drawdown

Primary productivity in the existing conditions is based primarily on phytoplankton, a result of the deep, slow-moving waters with fine sediment substrate. With sufficient flow, the accumulated fine material will be moved downstream. It is estimated that flows up to 200,000 cfs would be necessary to remove embedded sediments and return the substrate to its original sand, cobble, and bedrock (Hanrahan et al., 1999). A return to riverine conditions can allow the development of attached benthic algae and periphyton, which should replace phytoplankton as the dominant primary producers. Riparian conditions along the shoreline can develop, adding shade to shoreline waters and allowing input of allochthonous material, which will add additional organic material to the system.

The effects of the drawdown alternative on primary productivity can be estimated from modeling results as well as examining current data from free-flowing river areas. Comparison of the predicted total biomass of primary producers with measured biomass of primary producers from 1997 indicates that on a per unit length basis, primary productivity in the lower Snake River will likely be substantially higher under the natural drawdown alternative than under the existing impounded system. In addition, the bulk of the primary productivity will be shifted from the phytoplankton to the attached benthic algae component of the food chain. Total primary productivity is predicted to be higher under the drawdown alternative than in the existing impounded river. The predicted elevated algae production is a function of shallower water depths, increased water velocities, warmer water temperatures, and associated scour.

The biological data on primary producers for impounded and free-flowing river areas are very limited. Most of the available data is from the 1997 field effort. Diatoms dominate phytoplankton in the lower Snake River. Phytoplankton concentrations in the free-flowing section had a mean biovolume of 578,980 $\mu m^3/mL$, which was within the range of values observed in the impounded section, 323,697 to 738,062 $\mu m^3/mL$. However, river volume per unit of river length will be greatly

reduced for the drawdown alternative relative to the existing impounded river. As a result, the overall contribution of phytoplankton to system productivity is anticipated to be small.

Attached benthic algae will account for the majority of the total primary productivity for the natural drawdown alternative. The most extensive data for attached benthic algae were collected in 1997. This survey showed the free-flowing site to be more productive than the impounded sites with respect to chlorophyll *a* accumulations. On a dry weight basis, attached benthic algae at the free-flowing site averaged 24.02 mg/m² at a depth of 0.75 m. The other sites in the impounded section had dry weight values of 15.34 to 55.85 mg/m². There should be more substrate available for the growth of attached benthic algae following dam breaching than in the existing impounded river because shallower water depths will allow sunlight to reach more of the river bottom, resulting in increased growth of attached benthic algae.

Primary productivity will undergo short-term changes during and after the four-year dam breaching period. Hanrahan et al. (1999) estimated that sediments would be transported from Lower Monumental Reservoir within five years, so the transition period could be more than nine years, depending on the river location. Sediment transport would increase suspended sediments and turbidity, and following deposition, alter river topography. Primary productivity would likely decrease with decreased light transmission. Benthic colonization of new substrate may take several seasons to reach full productivity. Therefore, there may be a period of reduced primary production as primary productivity from phytoplankton is reduced but attached benthic algae have not yet fully colonized new substrate.

4.3.5 Secondary productivity

4.3.5.1 Existing Conditions: Existing System

The most common benthic macroinvertebrate taxa, which included both aquatic insects and the taxa, collected in Lower Granite, Little Goose, and Lower Monumental reservoirs from November of 1993 to September of 1995 were Oligochaetes, Amphipods (primarily Corrophiidae), Nematodes, Dipterans (primarily chironomids) and Pelecypoda (primarily mussels). In the hard substrate, Diptera (again primarily chironomids), Tricoptera (primarily caddis flies) and amphipods (both Gammaridae and Corophiidae) were the most common taxa. The insect larvae would provide a food source for salmonids.

4.3.5.2 Alternative A2: Existing System—Maximize Transport

Alternative A2 is similar to existing conditions, with the exception of the elimination of voluntary spills and maximization of transport. As factors affecting secondary productivity such as primary productivity, temperature, and velocity would not change with this alternative, secondary productivity would also not be expected to change.

4.3.5.3 Major System Improvements: Alternatives 2a, 2b, 2c, 6a, and 6b

The pathway alternatives 2a, 2b, and 2c differ only in terms of fish transport and are not expected to change any parameters that would affect biota. There should be no short or long-term changes in the species assemblage or density of herbivores. Alternatives 6a (with 1.0 MAF flow augmentation) and 6b (elimination of flow augmentation) will not alter the physical or chemical environment, and thus are not expected to alter the existing food web.

Alternative 6a, which has an additional 1.0 MAF of flow augmentation, is not expected to substantially change the type and level of secondary producers. Alternative 6b, which eliminates all flow augmentation, is expected to have minor changes in temperature and flow, with corresponding minor changes in primary productivity. No substantial short-term or long-term changes are expected in secondary producers compared to existing conditions.

4.3.5.4 Alternative 3: Natural River Drawdown

The drawdown alternative is expected to expose large littoral areas. It is estimated that riverine habitat following drawdown will compose approximately 39 percent of the available aquatic habitat in reservoirs (NAI and Bennett, 1999). Most of the habitat (90 percent) will be swift-flowing (greater than 2.0 fps) areas less than 14 feet deep during moderate summer flows. Most of the reduced velocity habitats will occur in narrow bands along channel edges. This will have a dramatic change on secondary producers.

The effects of the drawdown alternative on secondary producers can be estimated from modeling results as well as examining current data from free-flowing river areas. Few data exist on the composition of the aquatic insect or benthic animal community prior to construction of the dams. One study was conducted in 1973 upstream of the project area in a free-flowing section of the lower Snake River in Hells Canyon (Brusven et al., 1973). In the absence of any better information, the community observed during that study was assumed to be representative of what could be expected in the lower Snake River after breaching of the dams. The aquatic insect portion of this community would likely still have a high proportion of chironomids as is exhibited in the existing impounded system. Tricoptera would remain moderately abundant while Ephemeroptera (mayflies) and Lepidoptera would represent the balance of the community. Secondary productivity is expected to increase in response to increased primary productivity. Organisms that feed on attached benthic algae, such as aquatic insects, will experience the greatest increase.

There are no water quality standards for secondary productivity; therefore, no predictions can be made in terms of exceedances. The shift in secondary productivity from zooplankton to benthic species that feed on attached benthic algae, such as aquatic insect larvae, would ultimately result in a shift to benthic feeding fish, including salmonids. Increased secondary productivity will result in increased biomass of higher trophic levels, including those feeding on aquatic insects, as well as piscivores (salmonids, smallmouth bass, northern pikeminnow, and catfish). The change from a lacustrine to riverine system would be of particular benefit to fall chinook salmon, which rear in the lower Snake River and rely upon aquatic insects as a food source.

A transition period would be likely where the secondary producer community would in flux. As primary producers change from planktonic to benthic, with possible reductions during the transition, secondary producers would also be affected.

4.3.6 Food web

4.3.6.1 Existing Conditions: Existing System

The current food web in the lower Snake River is driven by phytoplankton primary productivity, with small contributions from attached benthic algae (Figure 3-28). Zooplankton is the primary herbivores, which are consumed by planktivorous fish. Aquatic insects are of lesser importance, and consumed by bottom-feeding fish. At the top of the food web are piscivores.

4.3.6.2 Alternative A2: Existing System—Maximize Transport

Alternative A2 is similar to existing conditions, with the exception of the elimination of voluntary spills and maximization of transport. As factors affecting the food web such as primary productivity, secondary productivity, temperature, and velocity would not change with this alternative, the food web would not be expected to change either in the short term or long term.

4.3.6.3 Major System Improvements: Alternatives 2a, 2b, 2c, 6a and 6b

Major system improvements Alternatives 2a (maximized transport), 2b (minimized transport), and 2c (adaptive management) are not expected to change primary or secondary producers. Therefore, no short-term or long terms change in the food web are expected to result from these alternatives.

Alternative 3: Natural River Drawdown

Recent biological productivity modeling indicates that upstream areas in the lower Snake River would experience a major shift in the primary productivity components and potentially an overall net gain in primary productivity under the natural river drawdown alternative (Figure 4-13). Results from the biologic model indicate that benthic algae throughout the lower Snake will dominate the primary productivity following dam breaching. Phytoplankton productivity will be of relatively lesser importance. Total primary productivity under the drawdown alternative is predicted to increase in comparison to the existing impounded river. The fish community following drawdown will likely consist primarily of benthivores rather than the mix of planktivores and benthivores in the existing system. Benthic algae, aquatic insects, and benthivorous fish production are predicted to be highest during dry years. The elevated benthic algae production is a function increased light penetration, warmer water temperatures and shallower water depths and decreased water velocities and associated scour. The elevated aquatic insect and benthivorous fish production is a function of increased benthic algae production. The greatest changes in secondary productivity can be expected to occur in those trophic levels that feed directly on the attached benthic algae, with fewer effects in higher trophic levels. The top piscivores will likely remain northern pikeminnow and smallmouth bass, but the transfer of the bulk of the energy from primary productivity will be through the pathway that includes attached benthic algae, macrophytes, aquatic insects, benthic animals, and benthivorous fishes. Phytoplankton and zooplankton will become minor components of the food web. There are no water quality standards related to the food web. Salmonids will benefit from the change from a reservoir-based system to a riverine system. The secondary producers will change to mainly aquatic insect larvae, a preferred food source. In addition, increased flow and reduction in fine sediments will provide better habitat for salmonids. The shift in habitat and food sources will be especially beneficial to fall chinook, which spawn and rear in the lower Snake River and prefer low-velocity sandy habitat less than 6m (20 feet) deep (Bennett et al. 1993).

A transition period could be expected over the short term, where planktonic production is low, but benthic production is not yet fully developed. Planktivorous species would have less food available, but production for benthic species would not be fully developed.

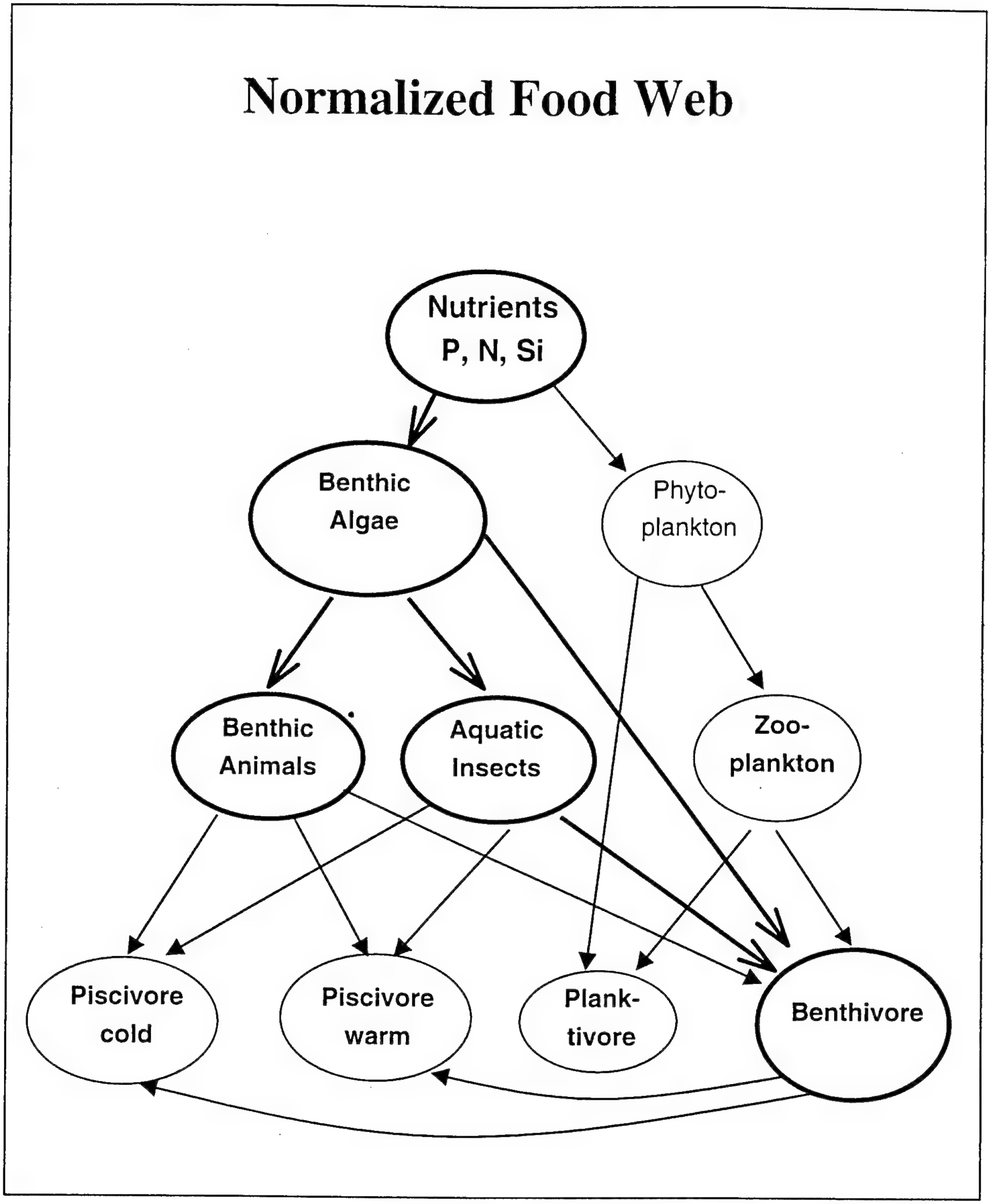


Figure 4-13. Generalized Food Web, Normalized Lower Snake River

5. Summary

Eight alternatives are under consideration to improve conditions for salmon on the lower Snake River. These alternatives are anticipated to have various effects on water quality parameters such as temperature, total dissolved gas supersaturation, sediment transport and erosion, primary and secondary productivity, and the food web. The anticipated impacts can be summarized as follows:

Existing Conditions: Existing system (A1) and Maximize transport (A2) alternatives: Water quality will not change under these alternatives. Reservoir areas will continue to age, with continued silt deposit, leading to an increase in eutrophic conditions.

Major System Improvement Alternatives A2a (Maximize Transport), A2b (Minimize transport) and A2c (Adaptive Management): These three alternatives will not cause major changes in water quality parameters or primary and secondary productivity compared to existing conditions.

Major System Improvement Alternative A6a (Additional 1.0 MAF augmentation): The additional 1.0 MAF flow augmentation will nearly triple flow augmentation volumes passing through the reservoirs. The additional flow will have limited ability to cool downstream waters and may, in fact offset Dworshak Reservoir releases. Peak temperatures will likely be elevated, especially in low-flow periods, accompanied by earlier fall cooling. The increased flow augmentation could also increase involuntary spill, resulting in higher TDG levels and longer periods when TDG is above the threshold. The increased flow is not expected to exceed a normal spring freshet; therefore, no substantial changes are expected in sediment transport or erosion. Primary and secondary productivity should not change in comparison to the range of existing conditions, and no change in the food web is anticipated.

Major System Improvement Alternative A6b (Zero flow augmentation): The elimination of all flow augmentation would result in water temperatures that are more affected by meteorological conditions than the existing system. It is expected that there would be fewer days with elevated temperatures compared to existing conditions. Minor changes in TDG could result from fish improvements an elimination of flow augmentation. Effects on biota, including primary and secondary productivity, should be minimal.

Natural River Drawdown (Alternative A3): The natural river drawdown alternative will change the river system from a lake-like to riverine. Flows would increase, water depth would decrease, and shoreline areas would become exposed. Water temperatures would warm more quickly and earlier in the season and cool more quickly compared to existing conditions. Peak temperatures would be higher than the existing system during low-flow conditions, but would be similar during average and high-flow years. Primary productivity would likely increase as a result of increased light penetration and, in low-flow years, higher temperatures; however, attached benthic algae would be the dominant primary producers. This is in contrast to the existing system, where phytoplankton are most important. Corresponding changes in the food web would be expected in response to the dominance by attached benthic algae. Benthic herbivores such as chironomid and trichopteran larvae would be more important than at present. The dominant fish species would likely remain the same, and energy transfer would be through a benthic rather than planktonic food web. A major effect will be the movement of sediment that has accumulated behind each of the dams. Total suspended solids and turbidity would increase in comparison to existing conditions, at least in the

short term, with the potential to settle and alter existing benthic habitats. The release of other water quality constituents currently attached to bottom sediments represent additional concerns. Of the organic and inorganic chemicals tested in the sediment samples collected from the lower Snake River and in their elutriates only the concentrations of dioxin TEQ, total DDT and manganese were found to exceed recommended water or sediment standards and, as a result, to be considered as CoCs. Based on the results of the revised Columbia River SOR HEC-5Q modeling, the resuspension and redeposition of total DDT and dioxin TEQ contaminated sediments, due to the implementation of the natural river drawdown alternative, would not result in exceedance of any currently recommended sediment quality standards.

The results of the revised SOR HEC-5Q model indicate that the concentration of manganese in the lower Snake River, following the implementation of the natural river drawdown alternative would exceed State of Oregon water quality standards for the protection of human health and the United Nations standards for agricultural use. These exceedances would be experienced at each of the four reservoirs of the lower Snake River, where several irrigation withdrawals are located.

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7. Glossary

Aesthetics: Of or pertaining to the sense of the beautiful.

Allochthonous: Pertaining to substances (usually organic carbon) produced outside of and flowing into an aquatic or wetland ecosystem.

Alluvium: A general term for all detrital material deposited or in transit by streams.

Anadromous fish: Fish, such as salmon or steelhead trout, that hatch in fresh water, migrate to and mature in the ocean, and return to fresh water as adults to spawn.

Anion: A negatively charged ion.

Anthropogenic: Changes made by human activity.

Augmentation: Increased river flows above levels that would occur under normal operation by releasing more water from storage reservoirs.

Basaltic: Having a texture of a hard, dense, dark volcanic rock.

Behavioral guidance structure (BGS): Long, steel, floating structure designed to simulate the natural shoreline and guide fish toward the surface bypass collection system by taking advantage of their natural tendency to follow the shore.

Benthic community: Aquatic organisms and plants that live on the bottom of lakes or rivers, such as algae, insects, worms, snails, and crayfish. Benthic plants and organisms contribute significantly to the diets of many reservoir fish species.

Benthivore: An organism that consumes bottom-dwelling organisms.

Biomass: The total mass of living tissues (plant and animal).

Biota: The animal and plant life of a particular region considered as a total ecological entity.

Biovolume: Volume of an organism available for consumption.

Bivalve: A mollusk such as mussel or clam, having a shell consisting of two hinged parts.

Bulkhead channel: Channel through which fish are carried upward through the turbines via a bulkhead slot if they are not diverted by turbine intake screens.

Bypass channel: Fish diverted from turbine passage are directed through a bypass channel to a holding area for release or loading onto juvenile fish transportation barges or trucks.

Cation: A positively charged ion.

Chironomid: An insect, midge, which has a benthic larval stage.

Chlorophyll *a*: A green plant pigment necessary for plants to produce carbon from sunlight.

Collection channel: Holding area within the powerhouse that fish enter after exiting the bulkhead slot.

Dam breaching: In the context of this FR/EIS, dam breaching involves removal of the earthen embankment section at Lower Granite and Little Goose, and formation of a channel around Lower Monumental and Ice Harbor.

DDT: An organochlorine pesticide compound.

Detritus: Dead plant material that is in the process of microbial decomposition (adjective: detrital).

Diatom: A unicellular or colonial algae (aquatic plant) having siliceous walls.

Dissolved gas supersaturation: Caused when water passing through a dam's spillway carries trapped air deep into the waters of the plunge pool, increasing pressure and causing the air to dissolve into the water. Deep in the pool, the water is "supersaturated" with dissolved gas compared to the conditions at the water's surface.

Drawdown: In the context of this document, drawdown means returning the lower Snake River to its natural, free-flowing condition via dam breaching.

Elutriate: Type of water sample created by mixing sediment and water.

Endangered species: A native species found by the Secretary of the Interior to be threatened with extinction.

Epithelial: Having membranous tissue, usually in a single layer, and forming the covering of most internal surfaces, organs and the outer surface of an animal body.

Eutrophic: A body of water in which the increase of mineral and organic nutrients reduces dissolved oxygen, producing an environment that favors plant over animal life.

Exopthalmia: Having an abnormal protrusion of the eyeball

Fauna: Animals collectively, especially the animals of a particular region or time.

Fecal Coliform Bacteria: A group of organisms belonging to the coliform group and whose presence denotes recent fecal pollution from warm-blooded animals.

Federal Columbia River Power System: Official term for the 14 Federal dams on the Columbia and Snake rivers.

Feral: Existing in a wild or untamed state.

Fish collection/handling facility: Holding area where juvenile salmon and steelhead are separated from adult fish and debris by a separator and then passed to holding ponds or raceways until they are loaded onto juvenile fish transportation barges or trucks.

Fish guidance efficiency (FGE): Percent of juvenile salmon and steelhead diverted away from the turbines by submersed screens or other structures.

Fish passage efficiency (FPE): Portion of all juvenile salmon and steelhead passing a facility that do not pass through the turbines.

Flora: Plants collectively; especially the plants of a particular region or time.

Flow augmentation: Increasing river flows above levels that would occur under normal operation by releasing more water from storage reservoirs upstream.

Fluvial: Formed or produced by the action of flowing water.

Foraging habitat: Areas where wildlife search for food.

Forebay: The area of water directly upstream of a dam.

Freshet: A sudden overflow of a stream resulting from a heavy rain or thaw.

Gas bubble disease or trauma: Condition caused when dissolved gas in supersaturated water comes out of solution and equilibrates with atmospheric conditions, forming bubbles within the tissues of aquatic organisms. This condition can kill or harm fish.

Geometric mean: Average of $\log_{10}$ (original value +1).

Geomorphology: The systematic examination of landforms and their interpretation as records of geologic history.

Hydrology: The science dealing with the continuous water cycle of evapotranspiration, precipitation, and runoff.

Impoundment: Accumulated water in a reservoir.

Inundation: The covering of pre-existing land and structures by water.

Irrigation: Artificial application of water to usually dry land for agricultural use.

Juvenile fish transportation system: System of barges and trucks used to transport juvenile salmon and steelhead from the lower Snake River or McNary Dam to below Bonneville Dam for release back into the river; alternative to in-river migration.

Lacustrine: Of or pertaining to a lake.

Larva/larvae: An early life stage of an animal.

Limnology: The study of the physical, chemical and biological aspects of lakes.

Littoral zone: The shore area along a body of water, usually a lake, down to the depth of 10 meters

Lower Snake River Hydropower Project: The four hydropower facilities operated by the Corps on the lower Snake River: Lower Granite, Little Goose, Lower Monumental, and Ice Harbor.

Macroinvertebrate: Organism without a backbone generally measuring more than 0.5–1mm in size.

Macrophytes: large, vascular aquatic plants that grow in shallow water along the shorelines of lakes or in the slow-moving reaches of rivers.

Megawatt (MW): One million watts, a measure of electrical power or generating capacity. A megawatt will typically serve about 1,000 people. The Dalles Dam produces an average of about 1,000 megawatts.

Metamorphic: Rock that has been greatly altered from its previous condition through combined action of heat and pressure.

Minimum operating pool (MOP): .The bottom one foot of the operating range for each reservoir. The reservoirs normally have a 3-foot to 5-foot operating range.

Mitigation: To moderate or compensate for an impact or effect.

Mollusk: Any member of phylum Mollusca, largely marine invertebrates.

National Environmental Policy Act (NEPA): An act, passed by Congress in 1969, that declared a national policy to encourage productive harmony between humans and their environment, to promote efforts that will prevent or eliminate damage to the environment and the biosphere, to stimulate the health and welfare of humans, to enrich the understanding of the ecological systems and natural resources important to the nation, and to establish a Council on Environmental Quality. This act requires the preparation of environmental impact statements for Federal actions that are determined to be of major significance.

Navigation: Method of transporting commodities via waterways; usually refers to transportation on regulated waterways via a system of dams and locks.

Outwash: Coarse-textured materials left by streams of melt water flowing from receding glaciers.

Passage model: Mathematical simulation of the effect of downstream passage (through eight Federal mainstem hydro projects) on the survival of juvenile salmonids.

Pelagic food sources: Food sources for aquatic organisms that live in the water column.

pH: An index of the hydrogen ion concentration in water, measured on a scale of 0 to 14. A value of 7 indicates a neutral condition, values less than 7 indicate acidic conditions, and values greater than 7 indicate alkaline conditions.

Physiographic province: A geographic region.

Phytoplankton: Drifting plants such as microscopic algae that nourish themselves from the energy of the sun; they are at the base of the food chain and provide a food source for bacteria, water molds, and zooplankton.

Piscivorous: Feeding on fishes.

Planktivorous: Feeding on planktonic organisms.

Pumping stations: Facilities that draw water through intake screens in the reservoir and pump the water uphill to corresponding distribution systems for irrigation and other purposes.

Recovery: The process by which the ecosystem is restored so it can support self-sustaining and self-regulating populations of listed species as persistent members of the native biotic community. This process results in improvement in the status of a species to the point at which listing is no longer appropriate under the ESA.

Reservoir fluctuation area: Area between the minimum and maximum pool levels of a reservoir which includes the littoral, wave-action, and inundation zones.

Resident fish: Fish species that reside in fresh water throughout their lifecycle.

Riparian: Ecosystem that lies adjacent to streams or rivers and is influenced by the stream and its associated groundwater.

Rip-rap: A permanent, erosion-resistant groundcover constructed of large, loose, angullar or subangular rounded stone.

Run-of-river: This describes hydropower facilities that do not have storage or the associated flood control capacity; run-of-river facilities essentially pass through as much water as they have coming in, either through the turbines or over the spillways.

Salmonid: Of or belonging to the family Salmonidae, which includes salmon, trout, and whitefishes.

Scour: Cleared, removed by water.

Scouring: Concentrated erosive action, especially be stream or river water, as on the outside curve of a bend.

Senescing: Aging, growing old.

Smolt: A young salmon at the stage at which it migrates from fresh water to the sea.

Spawning: The reproductive process for aquatic organisms which involves producing or depositing eggs or discharging sperm.

Spill: Water released through the dam spillways, rather than through the turbines. Involuntary spill occurs when reservoirs are full and flows exceed the capacity of the powerhouse or power output needs. Voluntary spill is one method used to pass juvenile fish without danger of turbine passage.

Spillway flow deflectors (flip lips): Structures that limit the plunge depth of water over the dam spillway, producing a less forceful, more horizontal spill. These structures reduce the amount of dissolved gas trapped in the spilled water.

Stilling Basin: A concrete-lined pool below the dam where water dissipates energy prior to flowing downstream.

Substrate: Substances used by organisms for growth in a liquid medium; surface area of solids or soils used by organisms to attach.

Surface bypass collection (SBC) system: System designed to divert fish at the surface before they have to dive and encounter the existing turbine intake screens. SBCs direct the juvenile fish into the forebay, where they are passed downstream either through the dam spillway or via the juvenile fish transportation system of barges and trucks.

Surface erosion: Movement of soil particles down or across a slope, as a result to gravity and a moving medium such as rain or wind. The transport of sediment depends on the steepness of the slope, the texture and cohesion of the soil particles, the activity of rainsplash, sheetwash, gullying, dry ravel processes, and the presence of buffers.

Surficial deposits: Unconsolidated alluvial, residual, or glacial deposits overlying bedrock or occurring on or near the surface of the earth.

Tailrace: The canal or channel that carries water away from a dam.

Tailwater: The water surface immediately downstream from a dam.

Talus: Accumulated fragments of rock and soil at the foot of cliffs or steep slopes.

Taxon/Taxa: Any level of classification, as genus, species, etc.

Terracing: Creation of a relatively level bench or step-like surface, breaking the continuity of a slope.

Thermocline: A density gradient due to changing temperatures within a water body.

Threatened species: A native species likely to become endangered within the foreseeable future.

Total suspended sediment (TSS): The portion of the sediment load suspended in the water column. The grain size of suspended sediment is usually less than one millimeter in diameter (clays and silts). High TSS concentrations can adversely affect primary food production and fish feeding efficiency. Extremely high TSS concentrations can impair other biological functions such as respiration and reproduction.

Transect: A line on the ground along where sample plots or points are established for data collection.

Trichopteran: An insect, caddisfly, which has a benthic larval stage.

Trophic level: Position in the food chain determined by the number of energy-transfer steps to that level.

Turbidity: An indicator of the amount of sediment suspended in water. It refers to the amount of light scattered or absorbed by a fluid. In streams or rivers, turbidity is affected by suspended particles of silts and clays, and also by organic compounds like plankton and microorganisms. Turbidity is measured in nephelometric turbidity units.

Turbine intakes: Water intakes for each generating unit at a hydropower facility.

Turbine intake screens: Standard-length traveling fish screens or extended-length submerged bar screens that are lowered into the turbine bulkhead slots to divert fish from the turbine intake.

Watershed: The area draining into a river, river system, or body of water.

Wetland: An ecosystem in which groundwater saturates the surface layer of soil during a portion of the growing season, often in the absence of surface water. This water remains at or near the surface of the soil layer long enough to induce the development of characteristic vegetative, physical, and chemical conditions.

Yearling: Salmon less than one year old.

Zooplankton: Tiny, floating animals that provide a food source for larger aquatic organisms such as snails and small fish.

For more information on the
Lower Snake River
Juvenile Salmon Migration Feasibility Study

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